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Reusable Launch Vehicles Operations and Maintenance Top-Down Analysis

Final Technical Report

Prepared for

Department of Transportation
Federal Aviation Administration
Associate Administrator for Commercial Space Transportation
AST-200 Licensing and Safety Division
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NOTICE

This report is a reissue of the 9/30/2002 report under the same title. This reissue was requested to incorporate final customer comments.

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Executive Summary

RTI was tasked with investigating Operations and Maintenance (O&M) activities and approaches that are practiced today by the traditional aviation domain and the Space Shuttle. In addition, this effort was to take into account the currently envisioned RLV concepts, and where possible, include a look at O&M activities already being used by the early commercial RLV developers. This report is the result of this effort. Information gathered during the preparation of this report was analyzed to determine where O&M rules and guidelines were needed immediately to ensure the public safety, as well as the approach that might be taken for creating such rules and guidelines. This report is intended as a resource for use in formulating an RLV O&M Notice of Proposed Rule Making (NPRM). This summary provides an overview of the research effort, a brief treatment of some of the most salient lessons-learned, a summary of the key recommendations, and a brief outline of next steps in accomplishing an RLV O&M NPRM.

Research Overview

Research for this effort was divided into three main activities across three areas. The activities included a review of a selected set of the Code of Federal Regulations (CFR), a data search and subsequent review of relevant industry documents and publications; and a number of interviews with industry participants. The three areas that were surveyed included traditional aviation, the Space Shuttle, and current and past commercial Reusable Launch Vehicle (RLV) programs.

As the work proceeded, specific functional and procedural areas emerged as logical groupings for which specific O&M considerations will need to be addressed in the future. These categories are as follows:

Systems Functions

1. Propulsion
2. Communication
3. Navigation
4. Flight Controls
5. Electrical/Wiring
6. Thermal Protection
7. Environmental Systems
8. Surveillance
9. Software
10. Propellant Management
11. Flight Safety System
12. Ground Support Equipment
13. Payload/Cargo
14. Structures
15. Avionics
16. Hydraulics
17. Pneumatics
18. Landing / Recovery Systems
19. Health Monitors & Data Recorders
20. Crew Systems
21. Facilities

Procedural Functions

1. Administration
2. Design Approval
3. Production Approval
4. Ground Operations Approval
5. Flight Operations Approval
6. Licensing
7. Launch Approval
8. Continued Flightworthiness
9. Problem Reporting & Tracking
10. Risk Assessment & Management
11. Safety Assurance
12. Mission Assurance
13. Training
14. Inter-&Intra-Agency Coordination

This set of functions and procedural areas served as the basis for identifying which aviation-related sections of the current Title 14 of the CFR were applicable to a given function, as well as how the lessons-learned from the aviation, shuttle, and RLV domains relate to each area. The 14 CFR sections reviewed for this phase of this effort were focused on procedural, as well as technical parts related to small aircraft. This focus was chosen since all indications are that initial RLV activities will be smaller vehicles, many of which are currently being developed for competition for the X-Prize. Correlations were also developed to lessons-learned during the investigation of aviation, shuttle, and RLV domains. The discussion of these correlations and the accompanying tables should prove useful for guiding subsequent RLV O&M NPRM activity. Detailed research for each of the functional and procedural areas is intended to be part of a planned functional analysis associated with a generic RLV in subsequent tasks.

Lessons-Learned Highlights

Lessons-learned were derived from the three focus areas of this research effort: Aviation Domain, Space Shuttle, and Reusable Launch Vehicles (RLVs). The concept of lessons-learned has been broadly defined to include all of those items that will require attention in defining an NPRM for RLV O&M. While some of these lessons relate to business or non-safety considerations, each should be reviewed for inclusion in regulation or accompanying guidance. Within each of these domain areas, topical areas were identified to allow the lessons-learned to be grouped together. For ease of tracking the lessons-learned, and to ensure that each lesson is considered as the NPRM proceeds, a tagging schema was developed that is intended to persist through subsequent phases of this effort, much like the system function and procedural areas are expected to carry-on to subsequent work. The remainder of this section provides a snapshot of some of the more important lessons-learned identified in via the top-down analysis.

Aviation Domain

Seven topical areas were identified for lessons-learned for aviation. The following table shows how the lessons-learned were distributed across these areas.

Topic Section	**Number of Lessons Learned**
Terminology	2
Rulemaking Process and Interagency Issues	15
Design, Maintenance, and Operations	8
Use of Approved Parts	6
Incident Reporting	5
Liability and Enforcement Considerations	3
General Operations and Maintenance Issues	24

In the area of terminology, the most frequent issue raised by looking at the aviation domain is the prevalence of the prefix ‘air’ as in airplane, airspace, and airmen. Since RLVs are being designed to operate not only in the atmosphere but in space as well, it would seem that a different prefix should be considered such as ‘aero’. While this seems a trivial issue, it speaks to a much broader topic of changing a mindset. Just as it has been suggested that the Federal Aviation Administration (FAA) be renamed the Federal Aerospace Administration, a serious effort will be needed to get people to think in terms of routine RLV operations so that limitations inherent in the existing NAS architecture can be overcome.

Rulemaking is a long process and once rules are on the books, it is often difficult to change them. Because of this, Federal Aviation Administration – Office of the Associate Administrator for Commercial Space Transportation (FAA-AST) should consider the development of a phased rulemaking effort that is designed to evolve as the RLV industry matures. This would be a more proactive approach than that found in the history of traditional aviation rules. It also carries with a downside, in that rules will have to be a little less specific and allow for more reliance on guidelines outside the formal CFR.

Operating characteristics and limitations are derived from design. New and novel designs may require new rules to be imposed. When parts are maintained or repaired the original operating characteristics and limitations should not be affected. When "major" repairs are made it is essential to conduct an analysis to assess if the operating characteristics and limitations are affected. There is a need to address definitions of major and minor. There is also a need to assure that the applicant cannot label a major change as minor by splitting it into multiple smaller changes to subvert the regulation.

Significant numbers and types of parts are approved through the Technical Standard Order (TSO) process (see 21.600). AST will need to determine whether a similar vehicle-type independent approval process can be used for RLVs. The presence of such a system, while primarily a design issue, also has large consequences for maintenance.

In absence of design approval, the issue of approved parts that is so central to traditional aviation maintenance becomes problematic for RLVs. It would seem appropriate to maintain processes like conformity for RLV’s, but the question is what is being conformed, and without design approval, does conformity have any value. Obviously, if processes like conformity are retained for RLVs, a mechanism for oversight and enforcement of the process must be put in place.

Finally, it needs to be recognized that many of the current aviation rules and the corresponding guidance, rely heavily on specific technologies and architectures sued across aircraft types. RLV flightworthiness requirements may vary depending upon the type of technology used in instrumentation (Flight critical instruments as well as Communication, Navigation and Surveillance) and fuel used. In addition to these differences between different RLVs, there is a need to consider the operational profile and limitations, design of housing, lubrication, vibration, working at altitudes, working at low temperatures, and high temperatures at reentry into the atmosphere. Since such decisions are not known today, and can be expected to evolve rapidly, the FAA must adopt rules that will facilitate, rather than hinder technological development.

Space Shuttle

Five topical areas were identified for lessons-learned for the Space Shuttle. The following table shows how the lessons-learned were distributed across these areas.

Topic Section	Number of Lessons Learned
Rulemaking Issues	5
Program Processes	13
Safety	12
Design and Technology	10
Maintenance and Operations	15

Specific transition criteria must be established. Systems and programs must have specific criteria established, reviewed, approved, and maintained for achieving operational status. (It should be noted that this requirement is applicable to commercial operations. Commercial operational status will be inherently different and should not be confused with NASA-operational status.)

Priority consideration should be given for critical problem resolution. Criticality ground rules, management requirements, and criteria for analysis must be rigidly followed.

E_C of $30x10^{-6}$ is comparable to the risk accepted by the public for commercial air travel (from 1982 through 1998, United States (U.S.) air carriers had 131 million departures, and accidents resulted in 2,868 casualties (354 serious injuries and 2,514 fatalities), which is equivalent to an E_C, of $22x10^{-6}$ per departure (NTSB, 2000, Tables 3 and 5, see Section 3.7.5.1.2)). The definition of the public is simply defined differently, people on the ground versus people onboard the vehicle.

It has been noted that the STS technology, though thirty years old, is not mature. Additionally, some of the testing is intrusive; therefore wear associated with testing must be considered in the Shuttle model. This is seldom the case for aircraft.

It was uncovered that the majority of the time spent in the Orbiter Processing Facility (OPF) are in four main areas: structures/mechanics/vehicle handling (26% of time), propulsion (18%), power management systems (16%), and Thermal management system (16%). This time was spent in three actions: unplanned testing and repair (29% of time on function), vehicle servicing (26%) and inspections and checkout (24%). The unplanned testing and repair drives the lack of confidence in the hardware dependability.

RLV

The same five topical areas from the Shuttle were retained for categorizing the lessons-learned for RLVs. The following table shows how the lessons-learned were distributed across these areas.

Topic Section	Number of Lessons Learned
Rulemaking Issues	15
Program Processes	3
Safety	12
Design and Technology	15
Maintenance and Operations	14

It is a necessity for the FAA to define what to design and operate rather than how industry should get to the performance standards. This includes the FAA determining the safety factor for design, operations, and maintenance.

In retrospect it would have been far easier and cheaper to execute all DC-X testing (except that involving cryogenic propellant flow) within the hangar versus on the pad. In keeping with “aircraft like” operations all vehicle systems tests should have both routine preflight and post flight procedures performed.

The use of an integrated ground and on-board automated systems checkout capability, initiated and controlled by the flight crew, was of profound importance in achieving rapid turnaround and minimal crew requirements. It should be the cornerstone of future system designs. It need not be overly complex; systems similar to those used on modern should be sufficient.

"Design for support" vs. "support the design" requires major increase in flight system maturity.

“Aircraft like” does not mean the vehicle has to look like an aircraft. It means that Operations and Supportability (O&S) considerations must be designed in at the beginning. Design for accessibility; ease of line item removal and replacement; avoidance of special fittings, connectors, fasteners or tools to perform maintenance; and following established (modified for peculiar rocket requirements) aircraft maintenance practices and tracking procedures, are but some of the “aircraft like” O&S techniques used successfully on the DC-X system.

Recommendations

As noted earlier, a series of correlations were made between the reviewed portions of the CFR and flight phases; between the reviewed portions of the CFR and the identified system functions and procedural areas; and finally, between the lessons-learned and the identified system functions and procedural areas. This data analysis resulted in a series of correlation tables that are intended for use in subsequent phases of the effort. In addition, they allowed the formulation of the following recommendations.

- Underlying rationale for the aviation FARs should be examined in order to formulate a parallel regulation for RLVs.
- FAA should determine the best taxonomy to use in organizing RLV rules and guidelines. Suggested taxonomies include:
  - Interaction with NAS i.e., starting with the current environment of use of Special Use Airspace (SUA) to gradually integrating the RLV launches and traffic into the air traffic. This makes for a phased approach giving ample time to work on changes that need to be made in the air traffic procedures.
  - Vehicle profile and capability of suborbital or orbital trajectories. There are currently vehicles of both of these characteristics and hence this taxonomy does not afford any relief in phasing.
  - Gross takeoff weight and number of passengers as in Part 23 and Part 25 of aviation. RLVs are expected to be small capable of only a few passengers in the beginning; rules should be established for these crafts before going on to larger RLVs capable of a number of passengers. This gives a phased approach to handle the type of vehicles as they are released in the market.
  - Rules specific to vehicle manufacturer, operator, and repair facilities. It is expected that that the RLV original equipment manufacturer will be the same as the operator for the near future. Third party repair and hand off of operation limitations may not need to be immediately addressed. This is similar to the current aviation regulations concerning experimental aircraft. As the industry matures, more complex scenarios such as third party production, repair and leasing etc should be phased into the rules.

- Rules should be general and high level so that they do not become obsolete as technology evolves.
- Guidelines should be released in conjunction with the rules to explain and apply the rules to most commonly used materials, methods and practices

in the industry. As special situations occur, issue papers may be written to cover unique issues. As this becomes commonplace, such guidance may need to be elevated to a rule. This would allow the FAA some flexibility to evolve O&M regulations along with rapidly evolving technology.

- Having a numbering scheme in parallel to Aviation FAR subparts will allow the users familiar with those FARs a quick access. However, it should be noted that the aviation FARs have like information distributed across many subparts and following the same pattern might make RLV regulations have the problems of scattered information. Actual packaging is less important than the contents of the rule.
- RLVs should be designed for maintainability. The FAA should impose Continued Flightworthiness rules that would address preventive maintenance by the way of the safety program specified in 14 CFR 431. Maintenance plan should be required as a part of license application. The FAA should require periodic reviews of such maintenance programs.
- The FAA should require development and delivery of an operating manual as part of the licensing application. This manual should contain operating procedures and any limitations unique to the vehicle design and its operating profile.
- The FAA should require reporting of discovery of a potential safety problem. Such problems, which may affect other RLV operators, should be made public to prevent incidents/accidents following the same model as Airworthiness Directives.
- Pilot training, curricula, eligibility, and training equipment should be approved by the FAA. It is recognized that these items may be unique to individual RLV changes.
- Since technologies used in different RLVs are diverse, technicians with demonstrated skill and background commensurate with the type of work performed should be licensed for that particular type of work until a standardized set of skills can be gleaned from a more established RLV industry in the future.
- The FAA should develop specific guidelines for the conduct of a Operational Readiness Review. This review should address the readiness of the crew, ground support personnel, and air traffic personnel, including coordination between FAA controllers and range and/or mission controllers.
- The FAA should develop specific guidelines for conduct of a Maintenance Readiness Review during the licensing process to assess the applicant's ability to maintain the vehicle in the same state of safety as when the vehicle is licensed.

Next Steps

Considerable work remains to arrive at a reasonable set of RLV O&M regulations and guidelines. This report provides a framework in the form of a specific set of system functions and procedural areas to be expanded upon in subsequent phases of this effort. The report also outlines a sequence by which further exploration of the aviation regulations, particularly for large aircraft and issues concerning operational approvals, need to be explored.

Building upon the lessons-learned from the three domains examined in this report, the next steps involve further data collection and analysis focused on each of the system functions and procedural areas. This effort is necessary to prepare for a functional analysis of either an actual RLV via a tabletop exercise similar to those employed during the licensing NPRM activity or against a generic RLV model. This preparatory phase will include identification of the current state of the art, best industry practices, and unique safety considerations associated with each system function identified in this report. Each procedural area will be explored to determine what models for accomplishing that process exist; if they do, whether they be adopted wholesale, or adapted for use with RLVs; and finally, how each of these processes fit within the broader context of the NAS and its evolution.

1.0 Introduction

Reusable Launch Vehicles (RLVs) will require new approaches to be developed for both Operations and Maintenance (O&M). These approaches may have a direct effect on the public's safety in or under areas where RLVs are being flown. The FAA has begun the process of establishing regulations and guidelines for RLV O&M to ensure appropriate visibility is provided to allow the FAA to accomplish their mission of ensuring public safety. This report provides the results of a top-down analysis of the O&M practices and regulations used by the existing aviation and space domains. Interviews, various publication reviews, and reviews of a selected set of the Federal Aviation Regulations [FARs, formally Title 14 of the Code of Federal Regulations (CFR)] were accomplished to identify lessons that could be used in the formulation of an initial RLV O&M Notice of Proposed Rulemaking (NPRM). Initial results from this effort were previously provided to the FAA in July of 2002.[1]

1.1 Purpose

The purpose of this report and the corresponding effort is to identify those Operations and Maintenance requirements that should be universally applied to Reusable Launch Vehicle maintainers and operators to ensure public safety and to allow for technological development and global competitiveness.

1.2 Background

FAA/AST produced a Phase I Rulemaking Project Record (RPR) covering *Licensing and Safety Requirements for Operations and Maintenance of Commercial Reusable Launch Vehicles* in June of 2001.[2] Version 1 of this RPR stated that this rulemaking process was to:

- Analyze the Federal Aviation Regulations and determining which are applicable or need to be modified to establish an adequate level of safety for commercial space reusable launch vehicles (RLVs) Operations and Maintenance (O&M).

- Draw upon National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) knowledge and experience to determine appropriate O&M standards and processes for commercial space RLVs from their experiences with the Space Shuttle and RLV Technology Demonstrators like the X-33, X-34, X-37, X-40A, and X-43 programs.

- Utilize the experience of the Commercial Space Transportation Advisory Committee (COMSTAC) RLV Working Group to determine appropriate RLV O&M requirements applicable to specific RLV concepts under development. Specifically, their safety-critical systems will be investigated, many of which are not similar to aviation systems. FAA research may be required to study these systems and concepts, especially if they utilize new materials and techniques.

- Work through the Commercial Space Transportation Integrated Product Team Working Group to ensure that the commercial space RLV O&M draft regulations that are developed have received a thorough review and their approval before becoming an NPRM.

- Develop a NPRM utilizing AST Resources and Contractor Support to determine the commercial space RLV O&M standards and processes necessary to provide an adequate level of public safety during commercial space RLV operations

RTI and FAA/AST discussed the above issues during a regular Program Management Review in January of 2002. This discussion included the work begun in the initial RPR and what was needed to produce the Phase II RPR. The resulting task, of which this report is the first deliverable, is designed to accomplish elements of the 14 CFR review, lessons-learned collection from the aviation, DoD, NASA, and current RLV efforts, and coordination with and through the Commercial Space Transportation Advisory Committee (COMSTAC) discussed in the Phase I RPR. The definition of this work was captured in a *Statement of Understanding (SOU)*, a top-level task description, to guide the initial work. Specifically, the SOU included the following three topics:

> *Topic 1*: Current practices and procedures to be researched will include a review of the STS, the aviation industry, and past and present RLV concepts. From these three focus areas a summary will be provided of the practices and procedures, covering the entire mission profile and operational phases, appropriate for developing RLV performance standards and the implication to public safety. These performance standards will be incorporated into a draft RLV O&M regulatory framework.
>
> *Topic 2* Research will investigate lessons learned from the regulation of commercial airline O&M practices, Shuttle experience, as well as current work of RLV concepts. From these three focus areas, the lessons learned appropriate for developing RLV performance standards and the implications to public safety will be summarized. These lessons learned will be incorporated into a draft RLV O&M regulatory framework.
>
> For *Topics 1&2* research will be provided in the form of a technical letter report. The organization of the final letter report may differ from the order given above. This work will serve to provide background information for the rulemaking support activity necessary for *Topic 3*.
>
> *Topic 3* A proposed NPRM outline and preliminary draft NPRM language will be synthesized from the material gathered in Topics 1 and 2. Guidelines to implement special case-by-case considerations will also be discussed in these proposed regulations.

Note: In subsequent meetings with the FAA, it was decided that this effort would not produce actual candidate text for the NPRM. Rather the goal should be on the development of a sound engineering basis for the rule content. An FAA-led team, using the results of this effort, will accomplish the actual drafting of NPRM text as a follow-on activity. Further, some of the terminology employed in the original SOU has been modified and updated as data has been analyzed from the various domains examined in the effort. For example, the phases of flight have been refined to more closely match those employed by both NASA and the FAA today. This report addresses Topics 1 and 2 of the SOU, and makes recommendations to allow activities discussed in Topic 3 to proceed.

1.3 Scope

As noted above, the scope of this effort is limited to data collection and corresponding synthesis for the purposes of ultimately creating *Licensing and Safety Requirements for Operations and Maintenance of Commercial Reusable Launch Vehicles*. Given the need to arrive at a set of Operations and Maintenance (O&M) requirements and guidelines that will both ensure the public safety and provide a consistent set of criteria for evaluating RLV license applications in as timely a fashion as possible, the scope has been further limited to include only a subset of the existing Title 14 CFR in this initial review. Primary emphasis has been placed on issues relating to smaller vehicles, both manned and unmanned. Additional issues such as security, international coordination, and integration of RLV operations within the National Airspace System (NAS) are not addressed in detail, but rather have been noted, where appropriate, as requiring further work. The specific criteria used to limit the data collection and synthesis effort are discussed in more detail in Section 2.1.3 and to a more detailed extent in Section 3.

1.4 Research Effort

The general model used in this research was to conduct a top-down analysis designed to identify “what” needs to be specified in any resulting regulations, and provide as much flexibility as possible in “how” individual RLV developers and maintainers perform their work.

Given the broad range of RLV concepts, proposed operations, and the general level of maturity of the industry, this research effort has been purposefully staged to allow for the most immediate safety issues to be worked first. Probably one of the most important outputs expected from this research effort is the development of a framework for overall O&M regulation and guidance as the industry matures.

This research effort is designed to gather Lessons Learned and best practices for Operations and Maintenance (O&M) from the aviation, Space Transportation System, and Reusable Launch Vehicle (RLV) domains; determine which of these items are necessary for ensuring public safety and that should be made a part of the regulations governing commercial RLV O&M; and determine where gaps exist that require further work before regulations or associated guidance can be created. In the development of this work a set of RLV Functions were identified and used to analyze the 14 CFR data as well as the lessons-learned data. These Functions were categorized into two groups: those that are related to RLV systems such as Propulsion, Communications, etc. These are referred to as System Functions in the remainder of the document. The second group contains those Functions having a procedural nature, such as Design Approval, Flight Approval, Licensing, etc. These are referred to as Procedural Functions in the remainder of the document.

Primary sources for this effort include the existing 14 CFRs found in Title 14 of the Code of Federal Regulations; work done previously by FAA on this topic including the RLV O&M White Paper [3] and associated industry comments coordinated through COMSTAC and the proposed "Aerospaceworthiness Standards" [4] written by Space Access Limited Liability Corporation (LLC); publications reviews from the O&M field, particularly those associated with Space Shuttle and aviation; and industry interviews.

In the course of conducting this research effort, every attempt will be made to determine answers to five of the seven questions raised in the Phase I RPR. These questions are:

1. How much of the existing 14 CFRs applicable to aircraft O&M can be utilized for commercial RLVs?

2. What new 14 CFRS may be required to be developed?

3. What regulatory safety guidelines need to be developed for this emerging industry to ensure public safety while new RLV O&M regulations are being developed?

4. Can innovative practices such as the FAA's designee program be used for RLV licensing the same as it is being used in the aviation arena?

5. What will the eligibility, knowledge, skill, experience, and medical requirements for an aerospace mechanic or repairman and how will they differ from an aviation mechanic or repairman?

Two additional questions raised in the Phase 1 RPR were deferred for this effort at the direction of the FAA. However, as will be noted, at least some information has surfaced which should help arrive at answers for the deferred questions. These two questions are:

1. What is the effect on RLV O&M requirements if humans are onboard?

2. What areas of research and development are required to conduct RLV O&M program that maintains the requisite level of safety?

While the overall O&M rulemaking effort remains a work in progress, this technical report summarizes the results of the first phase of data collection and analysis designed to answer these questions. A set of recommendations both for initial rules and a set of accompanying guidelines have been identified and can be found in Section 4 of this report.

2.0 Data Collection

Data collection was accomplished using a wide range of sources including literature and web searches, interviews, and detailed study of existing regulatory and associated guidance material. Three primary domains are explored in this report: aviation, various NASA efforts, and current RLV approaches.

2.1 Aviation Domain

Many comparisons have been made between the fledgling RLV industry and early aviation at the beginning of last century. This research effort is intended to draw as many lessons-learned from the traditional aviation domain as possible. The initial focus for this work has generally been on small aircraft since it is likely that the initial RLVs seeking formal licensing will carry small payloads or only a few passengers. By adopting such a focus, work associated with the contents of Title 14 of the CFR could be prioritized. This section captures the results from exploration of the aviation domain to date starting with a brief discussion of how regulations evolved for early aviation. Eventually, the RLV industry is expected to move towards large transport capable of carrying large payloads and a number of passengers. The regulations/guidance will evolve to address these issues as the industry evolves.

2.1.1 Regulatory Development – Historical Perspective

One of the questions that has frequently been raised relative to the sequencing of NPRM activity for RLVs is how was it done at the birth of aviation. This issue is of critical importance since over-regulation, aside from being extremely costly, can do irreparable harm to a nascent industry. In fact, many have argued that RLVs should be considered as purely experimental craft for the foreseeable future, thus placing them squarely in the camp of “fly at your own risk”. While this approach may seem favorable to some, it actually has the effect of harming the industry because of its deterrent effect on capital investment in the industry.

In an effort to determine if there are parallels to early aviation, a brief study of the regulatory evolution was conducted at the onset of this overall research effort. As is well documented in numerous histories, regulation of air travel in the US began under the auspices of the Commerce Department shortly after World War I. What is less well known is that there was actually considerable delay in arriving at a consistent set of regulations for aviation in the US. In fact, the US was a reluctant and late entrant to the world of aviation regulation.

In a large gathering of the world community in 1918, the *Convention Relating to International Air Navigation*[5] was created. Key components of this convention, which over forty nations adopted and subsequently formulated consistent national rules, included the following aspects germane to this current effort:

- Requirement for Certificates of Airworthiness and Competency

- Licenses for any Onboard Transmission Equipment and a Requirement to Carry Same for Aircraft Carrying more than Ten Passengers
- Prohibitions & Restrictions on Carriage of Explosives & Camera Equipment
- Special Allowances for State Aircraft

Annex B of the Convention went into the matter of Airworthiness Certificates in more detail specifying that "the design of the aircraft in regard to safety shall conform to certain standard minimum requirements; satisfactory demonstration of the aircraft design shall be accomplished through flight trials and these trials shall comply to a minimum set of requirements; "construction of every aircraft with regard to workmanship and materials must be approved"; aircraft must have appropriate instruments onboard for navigation; and finally, that individual states shall determine the minimum requirements discussed within the Convention [6][

From this early time in the history of aviation, the need to establish a minimum set of consistent, quantifiable rules to ensure public safety was recognized. In the US, it took another seven years to agree on and pass the Air Commerce Act of 1926 [7] that included the first requirements to satisfy international convention. The impetus for its passage came from industry that was greatly concerned about the possible loss of leadership in the rapidly expanding field of aviation, as well as the implications of liability and loss of military superiority. The subsequent statutes passed in 1938[8], and 1958[9] reaffirmed and strengthened the government's oversight role of all elements of the aviation arena. The rules have evolved as the oversight role has been expanded. Starting with aviation-related bulletins published by the Department of Commerce in the 1920's, the rules quickly evolved to Civil Aeronautics Regulations (CARs) and Civil Aeronautics Manuals (CAMs). These were recodifed in 1965 into the current Federal Aviation Regulations (FARs) contained in Title 14 of the CFR.

In formulating a set of O&M regulations at the onset of the RLV industry, the FAA is emerging from a purely reactive role to one of proactive regulation. The challenge to this effort and other similar work going on within commercial space is to develop an adequate set of regulations that will protect the public safety and at the same time not stifle innovation and become a hurdle for small companies hoping to carve out a niche in this emerging industry.

2.1.2 Aviation Current Practices

Aviation operations and maintenance practices have been evolving for more than a century and are generally well understood throughout the industry. The FAA provides significant oversight in the field through aviation inspectors and by the interaction with air traffic control and flight services. Basic flight rules compliance is required for all pilots, as is recurrent training and medical certifications. Operations associated with a specific type of aircraft are described by manufacturer-produced flight manuals that provide the operating characteristics and limitations associated with that particular airframe across all possible aircraft configurations.

Aviation maintenance is typically separated into two categories, routine or scheduled maintenance and non-scheduled maintenance. Scheduled maintenance is further categorized as line maintenance that generally occurs without removing the aircraft from service, and heavy maintenance which requires the airplane to be taken out of service and substantially disassembled. Significant work has been done to minimize unscheduled maintenance through a concept of Reliability-Centered Maintenance (RCM). Maintenance activities are required to be accomplished by trained and licensed technicians. This work must be accomplished using approved procedures, most frequently contained in an Original Equipment Manufacturer (OEM) maintenance manual that are also approved by the FAA. Manufacturers are also responsible for developing Instructions for Continued Airworthiness (ICA).

Volumes could be written on current aviation practices. To maintain focus on those items that would be most germane to the new domain of RLVs, interviews and publications reviews have been very carefully chosen to identify those models that would be most relevant to establishing initial RLV O&M rules and guidelines.

It should also be noted that the current aviation practices are predicated on an initial design approval of an aircraft and all of its component parts. Since this will not be the case, at least initially, for RLVs, many of the aviation practices are of limited applicability. Even though AST will not initially be performing design approvals, one model from the current design approval methods used for traditional aviation may prove useful in establishing guidelines for specific systems. The Technical Standard Order (TSO) defines a minimum set of requirements for specific types of equipment that are generic, i.e., they may be applied to a variety of vehicle types. This is an example where current aviation practices may be adapted for use by RLVs.

2.1.3 Title 14 CFR “FAR” Reviews

As a foundation for subsequent work on the RLV O&M NPRM, a review of a selected subset of the existing Title 14 CFR parts was conducted. Traditionally, the portions of Title 14 that contain the rules for aircraft, airmen, and related aviation topics have been referred to the Federal Aviation Regulations or FARs. The term FARs may be used interchangeably throughout this document where 14 CFR refers to aviation specific Parts of the code. This section describes the process used to determine the order in which the existing FARs would be reviewed and a brief summary of those reviewed during this portion of the research. A set of detailed matrices summarizing the selected FARs, as well as capturing questions/comments relating to their content, were developed to provide a reference for this effort going forward. These detailed matrices may be found in Appendix D.

2.1.3.1 14 CFR Review Phasing

There are over ten thousand pages contained in Title 14 of the Code of Federal Regulations. Given the urgency of developing a consistent and appropriate initial rule for RLV O&M, the research team reviewed the various RLV concepts currently under development along with their associated timelines. This information was compared with the existing 14 CFRs to determine an appropriate phasing of their review for the purposes of extracting lessons-learned and best practices from the aviation rules. Table 1, 14 CFR Review Phasing, provides the results of this review.

Table 1 14 CFR Review Phasing

Phase 1 Review (This Report)	Phase 2 Review	Phase 3 Review
1, 11, 13, 21, 23, 33, 34, 39, 43, 65, 91, 135, 139, 145, 147, 183, 381, 383, 400, 401, 404, 405, 406, 413, 415, 420, 431, 433, 435, 440, 450	21, 23, 25, 33, 34, 61, 63, 67, 73, 93, 95, 97, 99, 105, 119, 121, 135, 139, 142, 185, 187, 193	14, 15, 16, 17, 27, 29, 31, 35, 36, 45, 47, 49, 61, 63, 67, 71, 73, 77, 101, 103, 125, 129, 133, 137, 141, 150, 151, 152, 155, 156, 157, 158, 161, 169, 170, 171, 189, 198, 200, 201, 203, 204, 205, 206, 207, 208, 211, 212, 213, 214, 215, 216, 217, 218, 221, 222, 223, 232, 234, 240, 241, 243, 247, 248, 249, 250, 252, 253, 254, 255, 256, 257, 258, 271, 272, 291, 292, 293, 294, 296, 297, 298, 300, 302, 303, 305, 313, 314, 323, 325, 330, 372, 374, 374a, 375, 377, 380, 382, 385, 389, 398, 399

Note: Some of the FARs appear in multiple phases due to the wide range of topics covered by that part.

2.1.3.2 14 CFR 1 – Definitions and Abbreviations

14 CFR 1 provides a set of definition and abbreviations used throughout the aviation-series FARs. These definitions and abbreviations were reviewed in comparison with definitions and abbreviations routinely used in the RLV domain to identify any conflicts. Also, an attempt was made to suggest parallel terms for the RLV domain.

2.1.3.3 14 CFR 11 – General Rulemaking Procedures

14 CFR 11 includes the various stages of the rulemaking process, particularly those focused on solicitation of public input. This FAR was reviewed to identify any conflicts in the overall process and context with the current plan for completing the RLV O&M work.

2.1.3.4 14 CFR 13 – Investigative and Enforcement Procedures

14 CFR 13 contains the processes for determining non-compliance and the subsequent enforcement activities. It was reviewed to provide a comparison with 14 CFR 405, which was developed to address similar issues for commercial space.

2.1.3.5 14 CFR 21 – Certification Procedures for Procedures and Parts

14 CFR 21 deals with certification procedures for products and parts. This FAR has many elements of operations and maintenance during the design of products and parts. This review was used to identify recommendations for corresponding regulations for RLV O&M.

2.1.3.6 14 CFR 23 – Airworthiness Standards [Small Airplanes]

14 CFR 23 provides the various airworthiness criteria used to approve the type design for normal, utility, acrobatic, and commuter category aircraft. The purpose of this review was to identify operations and maintenance items that can be used for RLVs. Since design criteria is outside the scope of this effort, review of this FAR is being restricted to identifying those issues that directly relate to 14 CFR 91 and 14 CFR 43 operational and maintenance issues.

2.1.3.7 14 CFR 25 – Airworthiness Standards [Commercial Transports]

14 CFR 25, airworthiness standards for commercial transport category aircraft, is a parallel to 14 CFR 23. A cursory review of this FAR was conducted to determine any unique O&M issues for this report. While the approach differs slightly, and in some cases is more stringent than that employed for Part 23 aircraft, no major topical differences were noted. Further review of this FAR part is deferred to a later effort focused on large “transport” RLVs.

2.1.3.8 14 CFR 33 – Airworthiness Standards – Aircraft Engines

14 CFR 33 is concerned with airworthiness standards for aircraft engines. The review of this FAR was with the perspective of identifying particular features of engines that should be in the RLV O&M considerations. Although the types of engines and the corresponding technology used in the RLVs may be different from traditional aviation, there are similarities between the functions and precautions that can be built upon.

2.1.3.9 14 CFR 34 – Fuel Venting and Exhaust Emissions

14 CFR 34 deals with fuel venting, and smoke and exhaust emissions. This FAR has elements of Environmental Protection Agency (EPA) requirements that are imposed by the Department of Transportation oversight. This review was to identify establishment of technical basis for parallel regulations in RLVs, as well as the need for interagency cooperation.

2.1.3.10 14 CFR 39 – Airworthiness Directives

14 CFR 39 provides the FAA with a means of communicating an unsafe condition regarding a certificated item. This part of the regulation contains guidance for conditional use or disuse of the item. Continued use of the item without addressing the said unsafe condition constitutes a legal offence and is subject to enforcement action.

2.1.3.11 14 CFR 43 – Maintenance

14 CFR 43 provides the basic rules for maintenance, preventive maintenance, rebuilding, and alteration of aircraft. This FAR part contains qualifications of

personnel, record keeping and approval of return to service. This review was conducted to identify similar RLV requirements.

2.1.3.12 14 CFR 65 – Certification: Airmen other than Flight Crewmembers

14 CFR 65 provides the qualifications for certification of various airmen involved with aviation. These certifications include: air traffic tower operators, aircraft dispatchers, mechanics, repairmen and parachute riggers. For the purposes of this effort, particular attention was focused on mechanics, and repairmen that deal with mechanics and inspectors respectively. This FAR should be revisited when the concept of operations for an RLV gets more sophisticated as RLVs are more fully integrated into the NAS.

2.1.3.13 14 CFR 91 – General Operating and Flight Rules

14 CFR 91 deals with operating and flight rules that relate to design assurance (certification requirements), maintenance, flight rules, operations and rules for large and multiengine airplanes. Operating rules in specific flight regimes (political) and terrains (mountainous regions) are also discussed. This review was conducted by identifying parallel operation and maintenance issues for RLVs.

2.1.3.14 14 CFR 135 – Operating Requirements: Commuter and On-Demand

14 CFR 135 provides a set of guidelines for air carriers and operators who are being compensated for services or hire. It outlines the certification of such services and their operations. This FAR also has a tiered approach to regulations that get stricter as the passenger counts go up. Review of this FAR was focused on applicability to RLV O&M that is based on space tourism.

2.1.3.15 14 CFR 139 – Certification and Operations: Land Airports Serving Air Carriers

This part outlines the rules for certification and operation of land airports that serve scheduled and unscheduled passenger operations of an air carrier using aircraft with seating for more than 30 passengers. It does not apply to those airports designated as an alternate airport. This part is analogous to Part 420 License to Operate a Launch Site when considering RLV operations. 14 CFR 139 was reviewed with the perspective of identifying the rules that may be needed for an airport when RLV traffic is fully integrated with traditional aviation traffic in the National Air Space (NAS).

2.1.3.16 14 CFR 145 – Repair Stations

This FAR part contains rules for performance of repairing aircraft operating under part 121 and 125. Also discussed are domestic and foreign repair stations. Although a current need for RLV repair stations, either foreign or domestic, have not been established, this FAR was reviewed for applicability in the RLV domain.

2.1.3.17 14 CFR 147 – Aviation Maintenance Technician Schools

This FAR part contains certification requirements and operating rules for maintenance technician schools. These rules were reviewed for applicability to RLVs, particularly in view of comments received from COMSTAC on the RLV O&M white paper.

2.1.3.18 14 CFR 183 – Representatives of the Administrator

This FAR part contains requirements for designation of responsibility to examine, inspect, and test on behalf of the Administrator. This FAR was reviewed with the perspective of this system of extending the workforce of the FAA for the RLV domain.

2.1.3.19 14 CFR 381 – Special Event Tours

This part provides the guidance to ensure air travelers who have purchased tours to special events will receive the promised admission to the event. This FAR was reviewed for applicability to RLV operations when considering the space tourism aspect of the RLV industry.

2.1.3.20 14 CFR 383 – Civil Penalties

This FAR establishes the basis for the civil penalties for specific violations. It was reviewed to determine whether different or additional penalties need to be defined for the RLV domain.

2.1.4 General Publications Reviews

A large number of trade journals, web sites, and conference papers and reports were reviewed to extract lessons-learned, as well as to identify further sources to investigate and individuals to interview. This section provides short summaries for the most useful sources identified to date.

2.1.4.1 Air Transport Association (ATA), ATA MSG-3 Operator/Manufacturer Scheduled Maintenance Development, March 2002

This document is currently being used in the airline industry for developing their maintenance programs. It was developed by a Maintenance Steering Group (MSG) and is designed to apply airline and manufacturer experience to the development of a logical method for deriving efficient maintenance programs. The document has a long history of usage (MSG-1 developed in 1968), adaptation to new technology, and continuous improvement with participation from the airframe and powerplant manufacturers, airlines, and regulatory authorities from both US and Europe. The document considers both safety and economic issues and blends regulatory constraints to provide guidelines to establish scheduled maintenance procedures. Scheduled maintenance includes lubrication servicing, operational/visual check, inspection/functional checks, restoration, and discard.

The objectives of scheduled maintenance are

a. To ensure realization of the inherent safety and reliability levels of the aircraft
b. To restore safety and reliability to their inherent levels when deterioration has occurred
c. To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate

d. To accomplish these goals at a minimum total cost, including maintenance costs and the costs of future failures.

A group of non-scheduled tasks result from:

a. Scheduled tasks not accomplished at specified intervals
b. Reports of malfunctions
c. Data analysis

Derivation logic of Maintenance Significant Items (MSIs) is detailed as a separate and distinct process from the safety analyses performed as part of the design activities (per 14 CFR 25.1309). Certification Maintenance Requirements (CMRs) from the design process are considered as input to the logic process to derive MSIs.

There are a few fundamental characteristics that aided in the creation of such a guide. MSG-3 relies on design assurance and the willingness of the Maintenance Review Board (MRB) in using this method to prescribe the initial scheduled maintenance. The MRB is an integral part of the FAA's Aircraft Evaluation Group (AEG), part of the FAA's approach to certifying the design of new aircraft and engines. The airlines and manufacturers were open to sharing perspectives, observations and knowledge with opposing points of view, which were balanced in the construction of the maintenance schedules. With this broader base of knowledge, manufacturers are better able to address safety in their prescribed maintenance schedules and procedures. Airlines are better able to schedule their maintenance activities that, in turn, allows for more economic utilization of their fleets.

This model of opposing opinions, experience or a desire to share the knowledge does not yet exist among the RLV community. For a typical RLV, the manufacturer may be the same as the operator/maintainer. There are not yet multiple operators for the same RLV, although this development should be expected since most other forms of transportation have evolved in this way. Since there are many new design features being proposed for the various RLV concepts, there may not be a lot of information that can be shared between the designs. Even common components may experience different levels of stress and fatigue due to differences in RLV designs. Further, any information shared has the danger of being applied incorrectly when the designs are so varied. Maintenance schedules based on wrong assumptions may cause more safety problems. Design constraints and the development of forms deemed to be more efficient or safe are likely to lead to more homogenous designs, similar to that now prevalent in the aviation domain. This should enable an approach similar to the MSG-3 model. Even in the absence of such homogeneity, at least a portion of MSG-3 may be usable by today's RLV developers and the FAA. Specifically, the logic trees suggested by MSG-3 may allow for the initial definition of maintenance schedules. Please note that much consideration has to be given to

RLV operating characteristics, which are much more severe than an aircraft operating characteristics.

MSG-3 allows for Minimum Equipment Lists (MELs) to be used in formulating maintenance schedules and approaches. MELs are covered in 14 CFR 91.30. The manufacturer of an airframe provides a Master MEL (MMEL) that details specific aircraft systems or physical elements that must be present and in operating order so as not to degrade the airframes performance or render the aircraft non-airworthy. Note: The state of being airworthy includes refers to being both safe and in compliance with the appropriate regulations. Thus an aircraft can be safe, but yet be non-airworthy because of a regulatory problem (e.g., incomplete or improperly completed paperwork covering a repair or specific equipment installed). As an example of a performance issue related to the contents of the MMEL, consider that missing fairings on the outside of the airframe may increase the drag to a point that the specified performance for that airframe cannot be obtained. The MMEL will note the number of such fairings that can be missing before performance is so adversely affected. This is important for aircraft that operate to the edge of their performance limits such as long haul or acrobatic aircraft. An operator may add other restrictions and/or instructions for maintenance and operation personnel commensurate with their operating practices. Such changes result in an MEL unique to that operator. For example, an operator who routinely flies to a remote location may require additional levels of redundancy, i.e., more items working on the aircraft than required by the MMEL, so as not to strand the aircraft at the remote location in the event of a subsequent failure. This would be analogous to many planned RLV flight profiles where maintenance at the destination (suborbital or orbital trajectories) are unlikely to allow for any maintenance activities prior to touchdown.

2.1.4.2 Reliability-Centered Maintenance by John Moubray, Industrial Press Inc., Second Edition, 1997

This book provides a detailed treatment of Reliability-Centered Maintenance (RCM), a concept closely related to the approach captured by MSG-3. Greater automation has caused us to rely on the automation performing normally and reliably; down time for repair and maintenance could be very costly in terms of users time and inconvenience. Failures may also have serious safety or environmental consequences. Industry is shifting to design and production approaches with reliability and maintainability as key considerations. RCM builds on this by providing a model to maintain the reliability through periodic preventative scheduled maintenance rather than inconvenient and unexpected down time due to breakage. During such scheduled maintenance, scheduled restoration, discard or on-condition maintenance may be accomplished. When failures occur in spite of these scheduled activities, the root cause of the failure is determined and the capability of the system is redesigned from the lessons learned. Greater maintenance cost effectiveness is achieved by this method.

Failure Modes and Effects Analysis (FMEA) forms the basis for this method. Using FMEA, functional failures and their consequences are analyzed. This allows subsequent actions to be taken that will prevent future failures by way of a proactive maintenance task. There may be some failures that cannot be easily predicted or prevented; these may be serious enough to warrant redesign. In some cases a deliberate decision may be made to let the failure occur if the consequences are not serious. Logic diagrams and decision worksheets are used to analyze pros and cons of predictive and preventative maintenance. These analyses result in work packages, which are incorporated into routine maintenance, that are designed to ensure that personnel with the needed training and the appropriate procedures accomplish the needed maintenance activity. It is possible that some failure modes have been wrongly assessed and some may have been left out. The relationship between age and failures is also not very precise especially if the operating environment and conditions do not have a long history. RCM provides many of the same processes and techniques found in MSG-3 and should be a viable model for helping establish RLV maintenance approaches.

2.1.4.3 Aerolearn web class, Handling a Safety Audit – Class # SF132 (no date), www.aerolearn.com

This class has many good points about how to encourage industry to comply with standards as well as how can companies or the regulators check whether or not they have compliance with the regulations. Although the class is designed to address only safety, there are many points that may be extracted to aid in drafting RLV O&M regulations.

There are two types of safety audits, internal and external. There is a checklist of goals for the operation from the Flight Safety Foundation's booklet "The Practice of Aviation Safety" is as follows:

a. Do the policies, procedures, and practices provide appropriate and sufficient levels of safety and efficiency?
b. Are manuals, procedures, and standards understandable and are they being complied with?
c. Are the existing manuals, procedures, and standards valid for the current and projected operations?
d. Is the support provided by other departments, outside organizations, and contractors contributing to the safety, efficiency and economy of our operation?
e. How can we monitor the operation to assure continued adherence to the established policies, procedures, and standards?

To this end, establishment of good policies (derived from regulations as well as specific design of the aircraft and normal practices of the operator) is essential to safe operations.

2.1.4.4 Aerolearn web class, Regulations 101 for Air Carrier Mechanics – Class # RG101 (no date), www.aerolearn.com

This power point presentation covers the background of FAA regulations, The aviation industry considered lessons learned from incidents and crashes to develop airworthiness standards contained in the earlier CAR 3 and the current 14 CFR parts 23, 33, 35, and 36 for small aircraft. Two items that make an aircraft safe is that the aircraft meets type design (when built as well as when altered) and meets conditions for safe operation (consideration of limits, maintenance, operation etc). Requirements to meet type design are in CAR 3 and 14 CFR 23 for small aircraft. Requirement to maintain continuity of the type design are in 14 CFR 21 certification (alteration), 14 CFR 43 maintenance (Recordation, performance rules), and 14 CFR 91 operation (Responsibility for airworthiness, recordation, required maintenance and required inspection).

2.1.4.5 Aviation Maintenance, Overhaul and Maintenance (MRO), and MRO Management Magazines (Cumulative Review – Issues between 1999 and the Present)

A survey review was conducted of these three trade journals that serve the maintenance, repair, and overhaul market, primarily for commercial transport aviation. The majority of the issues surfaced were of much finer detail than those currently being considered in this NPRM activity. However, as Table 2, O&M Issues Identified from Maintenance Trade Journals, shows, there is considerable depth and breadth in the current aviation community. Such diversity should be expected in the RLV community as well. Note that these issues must be considered in the context of originally approved design. The paradigm in the traditional aviation domain is that maintenance exists to maintain a design as originally approved or to return it to that state in the event of a failure or after a defined period of use. Table 2 also provides an assessment of which of these issues may be considered common to both aviation and RLVs or unique to one or the other.

Note that many of these items represent areas where current FAA regulations for aviation are being challenged by technology advancement (e.g. satisfying FAA regulations for configuration management when using the Internet as a purchasing and tracking tool for aircraft parts).

Table 2 O&M Issues Identified from Maintenance Trade Journals

Issue	Aviation	Common	RLV
1. Repair tracking in the age of the Internet		X	
2. O&M one-stop-shops	X		
3. Original Equipment Manufacturer (OEM) versus Parts Manufacturer Approval (PMA) parts		X	
4. Environmental issues (e.g., noise abatement, emissions, etc.)		X	
5. Role of FAA in oversight of foreign carriers and their Civil Aviation Authorities (CAAs), e.g., International Aviation Safety Assessment (IASA)		X	
6. Flight Safety's Maintenance Resource Management (MRM) program		X	
7. Repair and alteration station approvals		X	
8. Outsourcing of routine maintenance and its effect on safety		X	
9. Aging aircraft issues	X		
10. Risk Management as a key prerequisite for operating approval		X	
11. 14 CFR 66 rewrite – industry concerns and issues (NPRM lessons-learned)	X		
12. 14 CFR/JAR (Joint Aviation Regulation (JAR)147 Training standards	X	X	
13. Two-tier maintenance technician approval (Expendable Launch Vehicle (ELV) vs RLV)?		X	
14. Recurrent training and ongoing oversight issues		X	
15. The dividing line between heavy maintenance and line maintenance		X	
16. Is there a "lifecycle" to RLVs?			X
17. Effects of a supplier furnished equipment (SFE) or buyer-furnished-equipment (BFE) decision on maintenance and operations, if any?		X	
18. Electronic manuals		X	
19. Flight Operations Quality Assurance Programs		X	
20. Maintenance, Repair, and Overhaul (MRO) Centers – total outsourced support		X	
21. "Damage-tolerance-based" inspections – aging craft issue		X	
22. High-Cycle Fatigue (HCF) –, engine related term		X	
23. Special flight regimes that require special conditions [e.g., Extended Twin (engines) Operations (ETOPS)]. Could inland launch or landing sites be considered a special condition		X	
24. "Lead airline process" and Civil Aviation Safety Team (CAST) initiative	X		
25. Aviation Rulemaking Advisory Committee (ARAC) – both good and bad	X		
26. Equipment calibration issues		X	

Issue	Aviation	Common	RLV
27. Environmental considerations in maintenance activities		X	
28. Aircraft On Ground (AOG) cooperation model		X	
29. Need to provide a focus on each element of operations, for example:			
a. Dispatch		X	
b. Flight Training		X	
c. Cabin Attendant Hiring and Training		X	
d. Maintenance		X	
e. Emergency Response		X	
f. Pilot Hiring and Training		X	
g. Security		X	
h. Passenger and Cargo handling		X	
30. The role of simulators and mockups in training and maintenance activities		X	
31. Human Factors[10] considerations at all levels		X	
32. 14 CFR 21.50 issues associated with Instructions for Continued Airworthiness		X	
33. Air Transport Oversight System (ATOS) – what should be the O&M quality system requirements?		X	
34. Return To Service (RTS) rules		X	
35. Suspected Unapproved Parts (SUPS), look at 14 CFR 3 effort		X	
36. Service Difficulty Report (SDR) system (14 CFR 121.703 and 14 CFR 121.074)		X	
37. Continuous Analysis and Surveillance (CASS)(14 CFR required maintenance trending)		X	
38. Fasteners, seals, bearings, and other standard parts		X	
39. Ramp rash and overall ramp operations, proximity to other aircraft and spacecraft		X	
40. BROAD issue for AST – How will operational and maintenance requirements ultimately be harmonized with other countries? Does the International Civil Aviation Organization (ICAO) have a role or is there a corollary group for space?			X
41. BROAD issue for AST - Operational and maintenance security issues – ultimately will Transportation Security Administration (TSA) have a commercial space aspect?			X
42. Leasing – longer term issue or immediate concern, effect on rules		X	
43. Special materials – maintenance activities – (e.g., Flight 587 composites, Shuttle heat resistant tiles)		X	

2.1.5 Special Topics

The following aviation topics were identified in the course of data collection as being of special interest in establishing RLV O&M regulations.

2.1.5.1 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) have no pilot on board. They are generally remotely controlled by a pilot on the ground, or in some cases may operate autonomously with only remote monitoring of their flight. Such vehicles are widely used in the DoD for reconnaissance, and increasingly for combat purposes. To date, the FAA has not finalized any UAV regulations. A set of Advisory Circulars (ACs) was drafted a number of years ago, and although never formally published, they are being used for UAV operations in civil airspace. The only formal UAV guidance that was found in the course of this research came from the Australian Civil Aviation Safety Authority. This section captures the reviews of both the draft FAA guidance and the Australian approved guidance. UAVs may be the foundation for integration of both autonomous and piloted RLVs in the NAS. While this may be more pertinent to the latter phase of deployment (i.e. Integrated NAS flight), UAVs may lay the ground work.

2.1.5.1.1 Pubs Review: Unmanned Air Vehicle Pilot Operations, DRAFT AC, dated June 19, 1996.

AC references the following 14 CFRs: 1, 45, and 91. In addition, the AC lists as related material, AC 61-27C.

The AC stipulates that the probability of hazard from a UAV should not be any greater than that from a conventional aircraft. This is stated as being 1×10^{-9} per flight hour.

The AC identifies two significant sources of risk associated with UAV operations that are distinct from those of manned aircraft. These are: absence of “see and avoid”, and lack of real-time control in the event of loss of signal from the ground.

The definitions provided in this AC include the terms launch and recovery. Launch covers activities up to 2000 ft Above Ground Level (AGL) or the maximum mission altitude if lower. Recovery covers flight activities below 2000 AGL or maximum mission height whichever is lower.

Unless specified in this AC or clearly not applicable to UAVs, Part 91 applies, the AIM, and other FAA guidance applies. (Note: This reviewer believes that this clause in the AC leads to considerable ambiguity and would be difficult to enforce as written.)

This AC is constrained to those UAVs with active human monitoring and control. All other UAVs must be constrained to SUA.

UAV operators are subject to rules governing drug and alcohol use including the eight hour exclusion period prior to flight.

The AC requires the existence and immediate access to flight manuals.

This AC contains extensive equipage requirements including anti-collision lights, position lights VFR-flight instrumentation (per 91.205), IFR-flight instrumentation (per 91.205), radar altimeters, communication systems, navigations systems, Flight Management System (FMS), Flight Termination System (FTS), transponder, weather radar, and onboard recorders.

The discussion of FTS requires automatic deployment if loss of ground control is lost and not reestablished within ten minutes. Non-explosive FTS is required if flying outside of restricted and warning area airspace.

The AC requires a flight plan and Letter of Agreement (LOA) 90 days prior to operations in the NAS.

Flight operations should be in controlled airspace. Flight in non-controlled airspace requires some form of collision avoidance capability. This may include chase planes, ground observers, onboard Traffic Alert and Collision Avoidance (TCAS), or other radars or sensors.

Right of way in flight operations should be given to manned aircraft, unless flying with a chase plane. In this instance 14 CFR 91.113 applies.

Notices to Airmen (NOTAMs) are required no less than two hours, but no more than 72 hours before UAV flight operations.

The AC requires a mission briefing via telecon or other means with the affected Air Traffic Control (ATC) facility(s).

The AC specifies a set of weather minimums similar to those for conventional aircraft.

The AC specifies numerous preflight and in-flight actions including determining airworthiness rules are satisfied prior to flight. In addition, contingency fuel requirements are provided, e.g. 45 minutes extra fuel for a 6-hour flight, 90 for a 12-hour flight, etc.

The AC concludes with sample Letters of Agreement (LOAs) and Notification letters.

2.1.5.1.2 Pubs Review: Unmanned Air Vehicle Design Criteria, DRAFT AC, dated July 15, 1994, initiated by ATP-200

AC references the following 14 CFRs: 21, 23, 27, 33, 35, 36, 39, 43, 45, and 91. In addition, the following additional references are noted as related reading: Joint Aviation Regulations-Very Light Aircraft (JAR-VLA), JAR 22, AC 21.17-3, 23-8A, and AC 23-11.

UAVs constitute a separate and distinct class of aircraft.

AC alludes to the wide variation in possible UAV designs and configurations. It also notes the difficulties this creates in coming up with a single set of guidance.

The AC introduces a number of new terms including the concept of internal and external pilots, an Air Vehicle Control Station (AVCS), and a definition of UAV that excludes the carriage of crew and passengers.

The AC establishes the safety criteria as equal to or better than a manned aircraft, both from the perspective of airborne and ground-based property or persons.

UAV registration / identification is required for the purposes of establishing reliability and failure rates. The standard registry would be used for this purpose.

In general, this AC requires similar design parameters to those used by conventional aviation. For example, static and dynamic structural loads must be demonstrated, fail-safe and fault-tolerant design mechanisms must be employed, equipage requirements dictated by airspace is required, software design assurance is required, health-monitoring and reporting is required, and appropriate FCC approvals for communication is required.

A flight termination system is required, one that avoids the use of explosives wherever possible.

The AVCS must provide for communications to Federal Aviation Administration (FAA) ATC.

Finally, an “equivalent level of safety” as that provided by “see and avoid” must be demonstrated. No guidance on how this might be accomplished is provided.

2.1.5.1.3 Pubs Review: Unmanned Air Vehicle Pilot Qualification and Training, DRAFT AC, dated June 18, 1996.

AC references the following 14 CFRs: 1, 61, 91, 141, and 143.

AC alludes to the wide variation in possible UAV designs and configurations that create difficulties in developing a single set of guidance. However for the purposes of integrating UAV operations into the NAS, it is recommended that a single set of minimum pilot qualifications be put in place.

The AC uses many of the terms contained in the other UAV AC and adds terms for Pilot In Command, and “Close Supervision of an Experienced UAV Pilot.”

AC requires a third class medical certificate, but allows for a waiver of barometric sensitivity [14 CFR 67.17(c)] as long as the certificate is marked “UAV Operation Only.”

The AC requires a private pilot certificate with a rating appropriate to the type of UAV, rotorcraft or fixed-wing.

The AC requires specialized ground instruction that discusses the “inherent differences” between conventional aircraft and UAVs. This instruction must include the differences present in the following areas:

1. Aerodynamics
2. Principles of flight
3. Structures
4. Flight controls
5. Electrical systems
6. Navigation systems
7. Propulsion systems
8. Communication systems (including the control data link)
9. Flight instruments, displays and their interpretations
10. Vehicle performance
11. Weather limitations
12. Navigations skills
13. Use of relevant flight Information publications

Knowledge of this information needs to be tested by an authorized instructor.

The AC requires training on the equipment that will be used to fly the UAV. Such training should be jointly agreed upon between the FAA, the applicant, and with consideration of the recommendations of the manufacturer. Such training must include normal, abnormal, and emergency procedures. A check flight is also required.

The AC stipulates recent experience requirements for both pilots and instructors for the purposes of retaining their certifications.

The AC further stipulates that the FAA must certificate providers of ground and flight instruction.

2.1.5.1.4 Pubs Review: Unmanned Air Vehicle Maintenance, DRAFT AC, dated June 19, 1994.

AC references the following 14 CFRs: 1, 43, 65, 91, 145, and 147. In addition, the following additional references are noted as related reading: AC 43-9B, AC 43-13-1A, 43-13-2A, AC 65-12A, and AC 65-15A.

AC alludes to the wide variation in possible UAV designs and configurations, which create difficulties in developing a single set of guidance.

The AC uses many of the terms contained in the draft UAV Design criteria AC and adds terms for collision avoidance lighting, pre and post flight inspections, and skill levels.

The AC requires that personnel performing inspection maintenance, and repair have “sufficient” skills to perform their functions. They should have previous experience working on aircraft and should be trained via formal, informal, on-the-job training.

Currency requirements should be established with an interim between activity or training not to exceed 24 months.

The AC contains a top-level set of guidance for the manufacturer, which would seem ideal for the initial maintenance guidelines associated with the O&M NPRM. These include:

1. Provision of inspection procedures
2. Provision of maintenance procedures
3. Provision of repair station procedures
4. Provision of in-flight diagnostics procedures

The AC also provides a general set of maintenance guidelines that draw upon AC 43.13-1A and AC 43.13-2A. It calls for adherence to manufacturer’s recommendations for inspection and overhaul whenever possible.

The AC requires a logbook for flight operations, as well as a log for repair and alteration activities. This log must contain specific data on parts used for the maintenance or alteration activity.

Built-in-test should be employed in the UAV design and should include provisions for indicating remaining emergency power in-flight.

Any onboard CAS system should be checked prior to flight. The FTS should be checked both pre and post flight.

Pre and post flight inspections should be conducted. Excessive wear or damage noted in a post-flight should remove the UAV from service pending investigation and correction.

2.1.5.1.5 Pubs Review: Regulatory Guidance from Australian Civil Aviation Safety Authority (CASA) including:

- **Unmanned Aircraft and Rockets, DRAFT AC 101-1(0), December 2001**
- **Rockets DRAFT AC 101-2(0), December 2001**

- **Model Aircraft DRAFT AC 101-3(0), July 2002**
- **UAV Aeroplane Design Standards, DRAFT May 2000**
- **UAV Rotorcraft Design Standards DRAFT, May 2000**

AC 101-1(0) provides a comprehensive treatment of UAV operational approval, design compliance, maintenance, and training. It covers most of the same material in a similar fashion to the FAA draft ACs. However, the Australian document appears to be more mature and is somewhat more flexible in its approach.

Unlike the FAA model, UAV operations are not restricted to SUAs except for flight-testing and certification. For normal operations, UAVs are treated in a similar fashion to routine IFR flights.

Transponders are required to allow for positive ATC, as is continual communication with the UAV pilot on the ground. Like the FAA approach, autonomous operation is allowed provided there is continuous monitoring.

Flight manuals and maintenance manuals are required. Training of the pilots and instructors is required. The safety standards are the same as those for conventional aircraft.

Seven critical subsystems are subject to design criteria for operations in IFR airspace. These are: flight controls, electrical, communications/data link, navigation, propulsion, UAV control station, and a flight termination system.

Small UAVs are exempted from registration requirements. Note: UAV size is discussed in the UAV Aeroplane Design Standards as having a gross takeoff weight under 800 kgs (approximately 1800 lbs).

Maintenance requirements must be identified in the form of Instructions for Continued Airworthiness, and should come directly from the vehicle manufacturer.

Medical assessment of UAV pilots is encouraged, but not directly required. An analogy to the driver of a motor vehicle is offered.

Ground and flight training are required, as is the issuance of an operating certificate for all small UAVs to be flown above 400 AGL and for all large UAVs.

Appendix 2 of AC 101-1(0) includes a fairly succinct treatment of the “fail-safe” design concept.

AC 101-2(0) discusses rockets in three classes: small, high-power, and commercial. For the purposes of this effort, only the commercial guidance applies. The AC states that commercial rockets must comply with the high-power guidance and are also subject to further licensing by the Department of Industry, Science, and Resources.

Note: CASA has created two design standards for fixed-wing and rotorcraft UAVs respectively. Since explicit design approval is not included within the scope of the current RLV O&M NPRM effort, these documents were not reviewed at this time.

2.1.5.2 Training

The FAA requires mechanics and repairman to have certain requirements, experience and skill level (14 CFR 65, Certificated Airmen Other Than Flight Crew). Mechanics and repairman can work on airplanes without having a certificate from the FAA. However, they cannot approve equipment for return to service, and they have to be supervised by FAA certificated supervisors. A mechanic certificate is of two types one for an airframe and the other for a powerplant. A mechanic can opt to get an inspection authorization through an application process and a test, which allows the mechanic to supervise other mechanics and repairman doing the work with the same rating. A repairman certificate is very specifically task oriented. Certificated repairmen can only work in FAA approved repair stations, commercial operators or air carriers where their certificated skills are used. A certificated repairman can supervise maintenance, repair or alterations of the same rating if the repairman understands the current instructions for continued airworthiness and the manufacturer instructions for the article undergoing repair. Experience, on-the job training or attendance in a FAA approved school are all different ways of qualifying for the certificates.

14 CFR 147, Aviation Maintenance Schools cover the FAA requirements for certification of schools. Facilities, equipment, materials, tools, instructors, and curricula are covered in these requirements. Operating rules for these schools include rules for enrollment, attendance, record keeping, certification awards, maintenance of the school facilities, maintenance of the curricula, and inspection.

14 CFR 43, Maintenance, Preventive Maintenance, Rebuilding, and Alteration, deals with rules for maintenance. This 14 CFR covers reporting requirements, hiring requirements, facilities, equipment, inspection, maintenance records, approval for return to service, performance rules and airworthiness limitations. These rules are interconnected with parts 91, 123, 125, and 135 for rules on inspections. Rules for operating a repair station (14 CFR 145, Repair Stations) depends upon what articles are being repaired- Type Certificate or a Technical Standard Order Authorization. Ratings of mechanics and repairmen have to match with the work that is being performed in the repair stations. Repair stations also have certification under different rating depending upon the article that is being repaired.

The FAA inspectors from the local FAA Flight Standards District Office (FSDO) have the authority to conduct inspections of certificated organizations such as schools and repair stations. They are also authorized to check the currency and validity of the certificates of the instructor, repairman, mechanic and the supervising mechanic or repairman. These guidelines are in the FAA Order 8300.10. FAA AC 145-3, Guide for Developing Repair Station Inspection Procedures and FAA AC 145-5, Repair Station Internal Evaluation Procedures are useful in establishing procedures at repair stations. AC 43-9C elaborates an acceptable way of keeping maintenance records.

2.1.5.3 Simulators

In the course of investigating training, the question of simulators as a training tool for both operations and maintenance was raised. While time did not allow an extensive research of this area including the detailed review of the relevant FARs, the following information was collected as a starting point for further exploration.

Simulators and flight training devices are covered in Aviation 14 CFRs 61, 141 and 142. FAA Flight Standards has the charter of assuring that airmen are properly trained. As part of their charter, they assure that the curricula, training devices and schools are qualified. The National Simulator Program (NSP) for the FAA is based in Atlanta AFS-205. This office is responsible for establishing simulation standards, qualification process, and a simulator QA process. Flight training devices are divided into levels depending upon the sophistication of its use. Simulators to train pilots on a specific cockpit have to be very sophisticated and accurate to represent that cockpit. A generic simulator does not have to be exact in its details of the location of the controls. Rules on the qualification of these training devices depend upon the level of the device. There are also rules on the duration and rigor of training that is required on these devices.

The Simulator levels and requirements are in Table 3:

Table 3 General Requirements for Flight Simulators by Levels (AC 120-40B)

Level	Control Loading	Visual Scenes	Motion	Visual Field of View (Note 4.)	Ground Handing Package	Runway Contam-inants	Sound	Buffets	Radar
A	Static	Night	3 Axis	45x30					
B	Static	Night	3 Axis	45x30	Yes			Yes	
C	Static & Dynamic	Night & Dusk	6 Axis	75x30	Yes	Feel	Cockpit Noise	Yes	
D	Static & Dynamic	Night, Dusk & Day	6 Axis	75x30	Yes	Feel & See	Realistic Cockpit Noise	Characteristic, Compliance Statement & Test Required	Operating Radar (Note 5)

Notes:

1. For training, testing, or checking credits consult the appropriate Practical Test Standards appendices and the regulation that the training, testing, or checking is to be conducted under.

2. Copies of the Practical Test Standards my be found at http://www.mmac.jcbi.gov/afs/afs600/akt.htlm.

3. Copies of the Federal Aviation Regulations may be found at http://www.faa.gov/avr/afs/14 CFRS/14 CFR_IDX.HTM.

4. Per pilot simultaneously.

5. When display is on pilot's navigation display.

Simulators have been reclassified into seven levels of Flight Training Devices (FTDs) in order to simplify the model of leveling. This model accommodates use of Flight standards for the qualification of more routine portions of the FTDs. FTD levels and their requirements are listed below in Table 4.

Table 4 General Requirements for Flight Training Devices by Levels (AC 120-45A) 08/17/2000

Level	Cockpit	Aerodynamic Model	Control Loading	Sound System	Motion System	Visual System	NSP Document Approval
1 (Note 1)							
2	Generic (Open or Closed)	Generic	No (Note 7)		Optional (Note 2)	Optional (Note 2)	Reference Data
3	Generic (Closed)	Generic	Yes	Yes	Optional (Note 2)	Optional (Note 2)	Reference Data
4	Specific for Make/Model (Open or Closed)	Not Required (Note 6)	Not Required (Note 6)		Optional (Note 2)	Optional (Note 2)	
5	Specific for Make/Model (Open or Closed)	Generic	No (Note 7)		Optional (Note 2)	Optional (Note 2)	Reference Data
6	Specific for Make/Model (Closed)	Specific for Make/Model	Yes	Yes	Optional (Note 2)	Optional (Note 2)	Qualification Test Guide
7	Specific for Make/Model (Closed)	Specific for Make/Model	Yes	Yes	Optional (Note 2)	Optional (Note 2)	Qualification Test Guide

Notes:

1. Level 1 FTD's are those ground training devices previously issued a letter of authorization by AFS-800 and given authorization to operate under 61.4 (b). See the National Simulator Program web page for further information at http://www.faa.gov/nsp/simftd3.htm.

2. Visual and motion systems standards set out in AC 120-40B for at least Level A simulators.

3. For training, testing, or checking credits, consult the appropriate Practical Test Standards appendices and the regulation that the training, testing, or checking is to be conducted under.

4. Copies of the Practical Test Standards my be found at http://www.mmac.jccbi.gov/afs/afs600/akt.html#pts.

5. Copies of the Federal Aviation Regulations may be found at http://www.faa.gov/avr/afs/14 CFRS/14 CFR_IDX.HTM.

6. If the Level 4 FTD has an aerodynamic program and is flown by the manual manipulation of the controls a control loading system is required.

7. Levels 2 and 5 need control forces and control travel only of sufficient precision to manually fly an instrument approach.

Level 1 FTDs do not require qualification. Qualification of levels 2 through 5 FTDs are largely delegated to the local FAA Flight Standards Offices, with the NSP office in Atlanta providing oversight and some review. Levels 2, 3 and 5 require an aerodynamic model and must be approved by the NSP. Level 4 does not require this model. A Qualification Test Guide is the document designed to validate the performance and handling qualities of a flight simulation device, within prescribed limits, agree with the airplanes and that all of the regulatory requirements are met. The Master Qualification Test Guide is the FAA approved Qualification Test Guide and contains results of FAA witnessed tests and serves as a future reference. To ensure consistency, this Master Guide is always reviewed by the NSP office in Atlanta.

2.1.5.4 Safety Reporting Systems

There are many programs in the aviation domain that collect, analyze and share information regarding safety incidents in order to learn to avoid future incidents and accidents. These programs include:

- The Aviation Safety Reporting System (ASRS)
- Flight Operational Quality Assurance (FOQA)
- Aviation Safety Action Program (ASAP)
- DoD-FOQA
- GAIN

The Aviation Safety Reporting System (ASRS) was established in 1975 under a Memorandum of Agreement between the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). FAA provides most of the program funding; NASA administers the program and sets its policies in consultation with the FAA and the aviation community. The current ASRS addresses reporting requirements, forms, immunity policy (prohibition against using data for enforcing purposes), de-identification of data, data processing and availability requirements. The regulatory basis for the immunity policy and reporting requirements comes from Advisory circular 00-46D, 14 CFR 91.25, Facility Operations and Administrative Handbook 7210.3M. ASRS data is being used for identifying deficiencies and discrepancies in the NAS, support policy formulation and planning of improvement to NAS, and strengthen the foundation of aviation human factors safety research.

Routine voluntary collection and analysis of in-flight data by means of a data-recording device by the airline operators is called FOQA. The data collected includes unusual autopilot disconnects, ground proximity warnings, excessive rotation rates on take-offs, unstabilized approaches, hard landings, and non-compliance with the operator's standard operating procedures. FAA is provided with de-identified data, which is then used for any policy improvements. De-identified data so collected is being used for improvements in flight-crew performance, air carrier training programs, operating procedures, air traffic control procedures, airport maintenance, and aircraft operations and design. The FAA monitors safety trends using the data and tracking the operator's effectiveness in correcting adverse safety problems. 14 CFR 13.401 prohibits the use of FOQA data for enforcement purposes in order to encourage the industry to participate in the program.

The objective of ASAP is to enhance aviation safety through the prevention of accidents and incidents. Its focus is to encourage voluntary reporting of safety issues and events that come to the attention of employees of certain certificate holders. To encourage an employee to voluntarily report safety issues even though they may involve an alleged violation of Title 14 of the Code of Federal Regulations (14 CFR), enforcement-related incentives have been designed into the program. An ASAP is based on a safety partnership that will include the Federal Aviation Administration (FAA) and the certificate holder, and may include any third party such as the employee’s labor organization. Order 1110.129, AC 120-66a, Handbook Bulletin for Air Transportation (HBAT) 00-88,

GAIN stands for Global Aviation Information Network. This is a program run by the FAA, system safety organization, to promote and facilitate voluntary collection and sharing of safety information by and among users in the international aviation community. The program supports sharing and use of:

- Industry best practices
- Existing tools and methods to develop new tools and methods
- Aviation safety data

The FAA is also committed to foster GAIN tools, reduce impediments to sharing, support and expand the GAIN infrastructure.

2.1.5.5 Experimental Aircraft Rules

Since RLVs are more like experimental aircraft, it is conceivable that the general path of the existing FAA guidelines for amateur-built aircraft may provide a useful model. The following ACs were reviewed for this purpose:

- AC 20-27E, Certification and Operation of Amateur-Built Aircraft

- AC 20-139, Commercial Assistance During Construction of Amateur-Built Aircraft
- AC 21-12B, Application for U.S. Airworthiness Certificate, FAA Form 8130-6
- AC 39-7C, Airworthiness Directives
- AC 65-23A, Certification of Repairmen (Experimental Aircraft Builders)
- AC 90-89A, Amateur-Built Aircraft and Ultralight Flight Testing Handbook
- AC 103-7, The Ultralight Vehicle
- Procedures for Experimental Certification (Excerpt from FAA Order 8130.2D, Airworthiness Certification Of Aircraft and Related Products -Internal Guidance for the FAA)

Ultralight vehicle operations are conducted only as sport or recreational activity. The operators are responsible for assessing the risks and assure their own personal safety. 14 CFR 103 rules apply. An Ultralight is not subject to FAA certification and maintenance standards. Since Ultralight operations are limited to single occupant operations, research in this area was not continued since it is unlikely to be of use for RLVs.

Amateur-built aircraft are defined as aircraft in which the major portion has been fabricated and assembled by person(s) who undertook the construction process solely for their own education and recreation. In the case of RLVs, although the space-tourists or passengers may not have had a part in the construction, it is expected that they understand and accept the risks. According to the current FAA-AST philosophy, it is the third party liability is most important since the third parties have not accepted the risk. As noted earlier, 14 CFR 21 contains certification procedures for products and parts. These procedures allow for the issuance of 8130-7, Special Airworthiness Certificates for aircraft considered experimental. Home-built aircraft may be built using existing designs (usually via a kit) or new designs. Commercially available components and parts may be used in the fabrication. The guidance requires the use of acceptable aeronautical construction standards and practices. The builder is also encouraged to consult with persons having expertise with aircraft construction techniques especially for the inspection of particular components such as wing assemblies and fuselages etc. A log should be maintained by the builder throughout the building process to prove that the aircraft qualifies for the amateur-built status.

There are no specific design standards that the FAA advocates. The FAA does not approve the design. The FAA inspects the aircraft for the use of acceptable methods, techniques and practices and issues airworthiness certificates with appropriate limitations. The FAA may deny an airworthiness certificate if the aircraft does not meet the requirements for the certification requested or if the aircraft is not in a condition for safe operation. There are operating limitations (Phase I Operating Limitations) that apply to the aircraft while undergoing initial flight tests, and then there are operating limitations (Phase II Operating Limitations) that apply after completion of the initial flight tests. Phase I Operating Limitations are appropriate for the applicant to demonstrate that the aircraft is controllable throughout its normal range of speeds and maneuvers and has no hazardous operating characteristics or design features. These test flights are usually conducted over water or over sparsely populated areas. After the test period the Phase II Limitations apply for an unlimited duration. Both Phase I and Phase II limitations are in Order 8330.2. The intent of these limitations is for the builder to demonstrate and maintain compliance with 14 CFR 91.319. The applicant and the FAA jointly review the limitations to assure common understanding. Testing instructions are detailed in AC 90-89A. Passengers are not allowed during the test phase. A placard in the aircraft in letters at least 3/8 inches in height, in a easily visible location to all persons entering the aircraft: "Passenger Notice: This aircraft is amateur-built and does not comply with federal safety regulations for standard aircraft." Operating rules are in 14 CFR 91. Maintenance records should comply with 14 CFR 91.417.

The aircraft is required to be registered before any airworthiness certificate is issued (14 CFR 21.173 and 14 CFR 47). There are also rules regarding the identification and registration marking (14 CFR 21.182).

The primary builder of the aircraft may be certificated as a repairman in order to maintain the aircraft in a condition for safe operation (14 CFR 43). The operating limitations may require certain inspections. The repairman certificate obtained by the builder solely with the purpose of maintaining the specific aircraft applies only to that specific aircraft and has to be surrendered if the aircraft is destroyed or sold. Compliance with Airworthiness Directives (AD) is also required (14 CFR 39). No person may operate a product, to which an AD applies, except in accordance with the requirements of that AD.

2.1.6 Interview Summary

A limited number of interviews in the aviation arena have been conducted with Aviation professionals who deal with FAA rules both from the regulator perspective and from the industry perspective. This section contains brief summaries from these interviews and is designed to highlight those items that are applicable to operations and maintenance aspects of RLVs as well as the rulemaking process/scope of rules. Note: Each of the individuals was given the opportunity to review and correct/amend the notes taken during the interview. The detailed notes from each interview may be found in Appendix E.

Please note: The following extracts are taken directly from the interviews conducted. Editing has been minimized to ensure the interviewee's original intent is maintained. Lessons-learned constructed from these interviews can be found in Section 2.1.7. The interview responses reflect the perspectives of the individual or their organizations.

2.1.6.1 Aviation 1: FAA Flight Standards Personnel Interview

1. Maintenance and operations policies for aviation originate in the design process.

2. Avoid subjective terms such as "Major" and "Minor". Avoid confusion, loopholes, and language that leads to uneven interpretation.

3. Provide backup and redundancy in inspections and audits - multiple inspections have proven to provide a safer system.

4. Continually observing the system for weakness and improvements and making the needed improvements will eventually lead to a safer system.

5. Record keeping can help both the regulators and the industry in improvements as well as alerting for problems in the maintenance and operations policy or practices.

6. Use plain language

7. Simplify organization

8. Separate regulations clearly for large operators and small operators

2.1.6.2 Aviation 2: Flight Safety Foundation Safety Auditor

1. Avoid language that can lead to misunderstandings and misinterpretations. Clearly spell out who is responsible for what.

2. Emphasize the connection between the designer point of view for maintenance and operator's point of view for operations and maintenance and the relationship. There is a need for specific operator policies for maintenance since the operator practices will affect maintenance.

3. Standard Operating Procedure (SOP) affect safety and should be required by regulation. The SOP should be kept separate from the operating manual. These two documents have different purposes and at different levels of abstraction in philosophy.

4. Tool calibration should be emphasized.

5. Fuel quality assurance - some operators do not know that it is their responsibility. Regulations should be clearly written to indicate this responsibility.

6. RLV operators may use parts brokers for aviation related parts. These brokers are not regulated and have been a source of unapproved parts; RLV operator liability should be clearly written into the regulations.

7. Clearly list the rules for "Return to service".

8. Assure that all of the educational material (advisory circulars, handbooks etc.) is made known to the industry.

9. Recognize that there will be no standard way of doing operations/maintenance. Allow for safety within these differences. Educate the industry in the intent behind the regulations.

10. Proactive regulations are better than reactive regulations.

11. Regulations should be worded in affirmative language rather than "do not" do this and that. This will promote better response from the industry.

12. Operators do not like having many masters. Currently they follow overlapping regulations from the FAA, Environmental Protection Agency (EPA), Department of Transportation (DOT) and Occupational Safety and Health Administration (OSHA). This gets to be complex. Convert these to a common reference for simplification.

13. Presentation/organization of regulations; make it easy to access, search and review. Some organizations such as Jeppesen sell tools that help. FAA should provide such tools.

14. Some form of quality and/or safety program should be required by the FAA.

2.1.6.3 Aviation 3: Cargo Operator

1. We should have more maintenance technicians involved in making the regulations.

2. Operations and maintenance policy is based on manufacturers manuals- based on design.

3. Reporting requirements: operators have a lot of reporting requirements. It is not clear whether or not any one in the FAA looks at these reports. A feedback system would encourage the operators to continue record keeping, improve record keeping and use this information to improve operations/maintenance as well as improve information exchange with the FAA.

4. It is better to have the mechanics trained in specific technology areas. The training schools should have targeted requirements.

5. Currently there are parts brokers who are not regulated. They may be selling bad parts. It is the responsibility of the operator to investigate whether or not a bad part is being sold. This is not well understood in aviation.

6. Repair stations are not audited often enough. There is room for improvement in the consistency of service by the repair stations.

2.1.6.4 Aviation 4: FAA Repair Station

1. Quality control procedures should be imposed.

2. Organizations training their mechanics may be beneficial.

3. Emphasize to the repair stations and operators, "Know your supplier." Brokerage world is suspect since it is not regulated.

2.1.6.5 Aviation 5: Trade Association

1. FAA has the authority to make changes to an operator's maintenance program in aviation. Operator's maintenance program is based on business decisions and should not be open for change by the FAA.

2. Make it clear to the operators as to what types of service difficulties must be reported.

3. There needs to be an arbitration system when there are differences in the interpretation of rules and regulations between the industry and the regulator or one regulator and another.

4. Need for clarifying and imposing Continuous Analysis and Surveillance (CASS), collecting the data that would help improve their maintenance program.

5. Proper application of regulations requires inspectors to make intelligent decisions rather than following a checklist.

6. Airworthiness Directives are onerous; there is a need for a process that is less onerous.

7. Rules are released before any of the advisory material is written. Even the preamble is taken out when the rule is released. There is a chance that some may not understand the intent behind the rules. It would be nice to see advisory material and rules be released at the same time.

2.1.6.6 Aviation 6: Airline Maintenance Facility

1. Make sure that the language of 14 CFRs is not subject to interpretation differently by different personnel - industry and different offices of the FAA.

2. Preserve consistency between regulations, guidelines and guidance.

3. Make sure that safety risks are well understood by both the industry and the FAA, and that the regulations are followed on a priority basis. For example, make sure that safety risks are mitigated on a priority basis over non-safety items.

4. Avoid making regulations on a reactive basis rather than a proactive basis.

5. Incorporate proactive checks rather than reactive checks for quality assurance and safety.

6. Do not impose non-value added requirements such as keeping of records that no one is planning to review or use.

7. Establish a safety division - an independent review of maintenance activities.

8. Reevaluation of rules including training requirements is needed to check the original intent and compare it to what is being required as technology evolves.

9. Evaluate what is being done at the system level for safety.

10. Appeals process without the fear of retribution needs to be put in place.

2.1.7 Aviation Lessons-Learned

Data from the review of a selected subset of the existing Federal Aviation Regulations (14 CFRs), interviews, review of trade publications and other data resulted in the identification of the following RLV specific issues. Some of these issues are currently worded in the form of questions where more research is needed to fully address the issue. Issues have been grouped by like-items. In addition, a numbering scheme has been introduced to identify each lesson within these groups. These numbers are used in Table 15 to correlate the lessons learned with both the system functions and procedural items (discussed in more detail in Section 3.6). Additional numbers have been reserved to be used in later phases of this research effort.

2.1.7.1 Terminology [AV1-AV50]:

In reviewing aviations terms and definitions, the most frequent issue raised relates to the prevalent use of the prefix ‘air’ as in airplane, airspace, and airmen. Since RLVs are being designed to operate not only in the atmosphere but in space as well, it would seem that a different prefix should be considered such as ‘aero’. This topic has been the subject of discussion within the COMSTAC. Their deliberations have been inconclusive. [AV1]

RLV literature should avoid use of terminology that may be used in the aviation domain with a different meaning. The only conflicting term that was recognized thus far is aviation term: “load factor". The aviation meaning of this term is the ratio of a specified load (aerodynamic forces, inertia forces, ground or water reactions) to the total weight of the aircraft. In space launch systems “maximum load factor” refers to either the maximum acceleration environment stated in g's or the maximum dynamic pressure a vehicle experiences. Whereas in space launch systems the only factor relative to the vehicle’s total weight is called mass fraction which is the ratio of a mass to the mass of the total launch vehicle at lift off (such as payload mass fraction: payload mass/total vehicle mass).
[AV2]

[AV3-AV50 Reserved]

2.1.7.2 Rulemaking process and interagency issues [AV51-AV100]:

Rulemaking process, particularly those focused on solicitation of public input, is a good process. This is in concert with the rulemaking process that is being proposed by AST. [AV51]

Airplane categories are per gross takeoff weight and number of passengers. This allows for tiers in regulations. It may be better to have different categories of RLVs with a proper taxonomy, which may or may not be weight or number of passengers. [AV52]

Specific requirements associated with operations are often related to and sometimes directly reference maintenance requirements. Is it possible to write 14 CFR 91-like regulation for RLVs in the suggested phased approach? What is the evolution of 14 CFRs in the phased approach? [AV53]

Current series 400 14 CFRs, especially "Basis and scope" (14 CFR Part 400) and "Organization and definitions" (14 CFR Part 401) should be reviewed after formulating the RLV regulations for any updates needed for accommodating new rules. [AV54]

Regulations relating to fuel venting, and smoke and exhaust emissions have elements of Environmental Protection Agency requirements. Interagency co-operation should be established in this regard. [AV55]

Regulations regarding frequency usage for communications may involve spectrum management issues and hence interagency co-operation with Federal Communications Commission should be established. [AV56]

Regulations regarding dangerous goods involve DOT interagency cooperation. [AV57]

Responsibilities for regulations regarding investigation of accidents may need to be established with NTSB for inter agency co-operation. [AV58]

The concept of operations for an airport when RLV traffic is integrated into traffic flow can conceivably different from the current airport operations. Issues of merging RLV operations with airport operations also need interagency cooperation, and possible changes in the current concepts of NAS operations. [AV59]

For RLVs, will there be specific operations depending upon political situations and terrain? Can this remain a responsibility of the operator? Are the political boundaries subject to international treaties? [AV60]

RLVs used by state agencies (for example use of RLVs by the United States Air Force for defense purposes such as surveillance and missile delivery) should be immune to regulatory procedures. This would be a corollary to state aircraft in the aviation 14 CFRs. [AV61]

One item that originated from the review of the aviation regulatory history was the greater reliance placed on technical advisory groups. The FAA may ultimately wish to expand or change the formulation of COMSTAC into a model similar to that employed by RTCA, formerly Radio Technical Commission for Aeronautics, for the aviation domain. [AV62]

Role of FAA in oversight of foreign carriers and their Civil Aviation Authorities (CAAs), e.g., International Aviation Safety Assessment (IASA) should to be defined for RLVs. [AV63]

The FAA should make sure that regulatory information as well as related educational and guidance material are easily accessible. It is better to release the guidance along with the rule so that the intent of the rules is not misunderstood. [AV64]

There needs to be an arbitration system when there are differences in the interpretation of rules and regulations between the industry and the regulator or one regulator and another. [AV65]

[AV66-AV100 Reserved]

2.1.7.3 Design, Maintenance and Operations [AV101-150]:

Operating characteristics and limitations are derived from design. New and novel designs may require new rules to be imposed. When parts are maintained or repaired the original operating characteristics and limitations should not be affected. When "major" repairs are made it is essential to conduct an analysis to assess if the operating characteristics and limitations are affected. There is a need to address definitions of major and minor. There is also a need to assure that the applicant cannot make a number of minor changes instead of a major change. [AV101]

Takeoff characteristics, flight characteristic, and landing characteristics their technical specifications, and materials used can continue to be safe only if these design characteristics are retained through maintenance and operations. [AV102]

Compliance for fuel venting and smoke and exhaust need to be established for RLVs. This is not just a maintenance issue; it is a design issue. Maintenance should assure that the design for fuel venting, and smoke and exhaust are not violated. [AV103]

Tests that are used in proving the design [i.e. those tests that in traditional aviation would be used to satisfy the requirements of type design data (see 14 CFR 21.31)] are good candidates for tests for "return to service" after maintenance activities. [AV104]

Installation, instructions for continued airworthiness, engine rating and operating limitations should come from the manufacturer. Maintenance activities must assure that these characteristics and limitations are not violated. [AV105]

Initial maintenance schedule should be established using design, and by simulating the operating conditions. [AV106]

Overhauling should be shown to not affect engine rating and limitations. [AV107]

Maintenance activities should not affect the original type design or operating characteristics or operating limitations of engines. The following areas may require specific verification activities to be repeated following maintenance and prior to return to service:

- Structural integrity relating to protection against, rain, hail, and foreign object ingestion
- Mechanisms used to provide additional margin of safety including fault tolerance such as redundant systems and dedicated safety systems including fire and vibration suppression
- Engines and engine-related subsystems may include a specific number of firings and critical component testing. [AV108]

[AV109-AV150 Reserved]

2.1.7.4 Use of Approved Parts [AV151-AV200]:

Significant numbers and types of parts are approved through the Technical Standard Order (TSO) process (see 21.600). Need to determine whether a similar vehicle-type independent approval process can be used for RLVs. Clearly we are not at that point now. Do we need to lay the foundation? Is it useful to recognize routine parts and instruments that already have a TSO in the aviation industry? [AV151]

What should be the definition of "approved part" to be used in repairs? There are security, as well as safety considerations, that may prevent U.S. from using parts not manufactured in the U.S. [AV152]

Should there be rules governing parts brokers? [AV153]

Requirements for checking expendables such as oxygen supply, spare parts on board, aging of spare parts, fire suppressants etc. should be noted in operational requirements for RLVs. [AV154]

Definition of "standard parts" should be established to relieve the FAA of the burden of scrutiny without sacrificing the safety margin. [AV155]

Use of aviation brokers for parts has not been regulated; RLV operators should be encouraged to survey the sources of their parts for suspected unapproved parts. [AV156]

[AV157-AV200 Reserved]

2.1.7.5 Incident Reporting [AV201-AV250]:

Incident reporting is important in knowing the effectiveness of the design and maintenance activities. Maintenance regulations need to address failure reporting; what problems/failures, how soon after finding a problem, who should report failures to whom, what information, in which format, how long to keep these records. [AV201]

Safety data recording and keeping this data in the public's eye so that all RLV operators can learn from each other's incidents and improve their operations. [AV202]

What should be the basis for a directive similar to Airworthiness Directive? [AV203]

Requirements for voice data recorders and black box recording should be established. [AV204]

Should there be routine recording of health and safety of instruments/ health and safety of persons on board at least for the first few flights of a particular RLV? [AV205]

[AV206-AV250 Reserved]

2.1.7.6 Liability and Enforcement Considerations [AV251-AV300]:

"Statement of conformity" (such as in 21.130) should be kept for RLVs- the applicant makes the statement of compliance and is liable even with the FAA oversight. [AV251]

There is a need for rules that ensure space travelers who have purchased tours will receive the promised services. This may be outside the purview of the RLV licensing process. However, it has a parallel in the aviation domain as a reflection on the economic viability of the carrier. This may also need to be coordinated with another government agency (e.g., Commerce Department) that may opt to handle it via existing consumer protections. [AV252]

There is a need to establish the basis and extent of civil penalties for violations of rules. [AV253]

[AV254-AV300 Reserved]

2.1.7.7 General Operations and Maintenance Issues [AV301-AV350]:

Although, RLV maintenance rules are being considered in the absence of type design, the intent of deriving the maintenance specific information from specific design should be retained. [AV301]

Maintenance procedures, schedules, inspection, and record-keeping requirements should be specified for RLVs. Information needed for these activities should be derived from specific design constraints - example: reliability of a certain part or appliance. [AV302]

Since there are different technologies used for gaining sub orbital state, the regulations should not impose a detailed list of all of the maintenance activities. The rules should be broad enough to cover specific wear and tear, specific operator differences, specific material/parts usage, etc. [AV303]

RLV space worthiness requirements may vary depending upon the type of technology used in instrumentation (Flight critical instruments as well as Communication, Navigation and Surveillance) and fuel used. In addition to these differences between different RLVs, there is a need to consider the operational profile and limitations, design of housing, lubrication, vibration, working at altitudes, working at low temperatures, and high temperatures at reentry into the atmosphere. [AV304]

Requirements for craft performance, and operating limitations should include weight, takeoff, and landing limitations as required for RLV flight. Additional requirements are needed to encompass RLV concepts and their flight regime. [AV305]

Requirements for flightworthiness, mechanical reliability reports, mechanical interruption, aircraft inspections and maintenance, preventive maintenance, and alterations programs should be applied to RLV O&M. [AV306]

Contents and format for manuals and markings (operating procedures, limitations, instructions for airworthiness etc) should be specified for RLVs. [AV307]

RLV operators should have the requirement to develop and maintain the carrier's operations manual encompassing key issues from safety considerations. [AV308]

RLV operators should have the responsibility to develop and maintain records for their service. These include mechanical irregularities, airworthiness checks, inspections and tests. Additionally, there should be requirements for pilots and co-pilots while under certain flying conditions as well as autopilot. [AV309]

Requirements for safety systems (fire protection, alerts, etc) are applicable to RLVs. [AV310]

Flight test requirements for "return to service" after maintenance should have specific criteria. There is some question as to how this could be handled within the current launch licensing process. "Return to service" could be one of the "authorized parameters" (14 CFR 431.3) evaluated in granting an operator license. It could be made an item that the "safety organization (14 CFR 431.33) is responsible for monitoring and ensuring compliance. [AV311]

Calibration and checking for the calibration of instruments used in testing and maintenance should be specified. [AV312]

Some amount of experience and training should be required for technicians and mechanics working on RLVs, particularly safety critical systems. What experience levels, and what skills and training may be substituted for this experience is the key question. [AV313]

Training is of particular concern in the areas of propulsion and propellant management. Mechanic ratings should be skill or technology specific rather than engine specific. [AV314]

Pilot in command responsibilities, minimum safe altitudes, Operations in different class airspace, use of safety belts, filing of flight plans, IFR radio communications, maintenance records, and maintenance required are applicable to RLV operations. [AV315]

Spacecraft and equipment requirements for operations should be considered in addition to those in operating rules in regulations parallel to Part 91. These requirements should be particular to an RLV concept, its Concept of Operations, and technology. Flight recording requirements should also be considered. [AV316]

The operating limitations for VFR and IFR flight as well as associated weather requirements for operations should be considered for flight through the atmosphere, and takeoff and landing. These requirements would have to consider horizontal/vertical takeoff or landing profiles, wake vortex, speeds in the terminal environment, etc. [AV317]

There should also be requirements for a secondary landing site. The applicability of alternate landing sites must account for cross range and downrange capability of an RLV. This would be synonymous with current aviation rules concerning emergency landing sites. It would also be useful to look at issues of aborting landings since RLVs may not have the capability for executing a Take-Off Go-Around (TOGA) maneuver. Finally, there is a relationship with the Flight Safety System to be considered. [AV318]

Requirements for the pilot in command and their operating experience and qualifications, as well as the prohibition of alcohol and drug use should be noted for RLV. More specific astronaut/RLV pilot requirements will be required in the stressing space environment. [AV319]

Flight time limitations and rest requirements for certification holders and their crews are applicable to RLVs. [AV320]

Requirements for tests and checks for pilots and crewmembers are needed for RLVs, but with modifications specific to operations for RLV flight. Requirements for a training program should be developed including curriculum for initial and recurring training. [AV321]

Adapt a reliability centered maintenance approach to establish maintenance schedules and programs. A program similar to the aviation CASS, Continuous Analysis and Surveillance, should be implemented for RLVs. There should be a proactive approach to inspection rather than waiting until a problem occurs. [AV322]

Special materials that will be used in RLVs should be tested for the harsh conditions of space travel, inspected often, and replaced often until sufficient confidence is gained. [AV323]

Use of Standard Operating Procedure should be mandated when RLVs share the airspace with NAS air traffic. [AV324]

[AV325-AV350 Reserved]

2.2 Space Shuttle

The only proven semi-RLV concept is the Space Transportation System (STS), referred to throughout this report as the Space Shuttle or STS. While significant data exists for the Space Shuttle all indications are that given the unique characteristics of Shuttle O&M, its use as a model for RLV O&M overall will be quite limited. This section draws together those items that look most promising from the shuttle experience base.

2.2.1 Space Shuttle Historical Perspective

The Space Shuttle, formally known as the Space Transportation System, was conceived and funded in the 1970's as a reliable and economical alternative to the single-use rockets of the Gemini and Apollo programs. Columbia, the first of the shuttle fleet to launch, began service in April of 1981. With the exception of the Challenger loss and follow-on design and procedural change period, the Space Shuttle program has been active with over 100 launches to date. While the Shuttle should not be thought of as a fully operational program (for reasons explained below), it does provide technical knowledge and procedures that can be used to extract lessons-learned.

2.2.2 Space Shuttle Current Practices

This section outlines the current practices of the Space Shuttle O&M procedures. While current practices and lessons learned from the Shuttle are useful, they are not directly applicable to future RLV processing nor O&M.

In order to fully understand the current Shuttle practices, it is necessary to examine an integrated process model, since it is such a complex vehicle with a multifaceted launch and return process.

2.2.2.1 Shuttle Processes

Shuttle ground operations include all of the activities involved in preparing the Shuttle for launch from its arrival at the spaceport until it leaves the ground. Note: launch is usually not included in the definition of ground operations for RLVs. NASA has developed a number of assessment tools for evaluating Shuttle ground operations, for example, the Shuttle Processing Flow Simulation (ShuttleSim), see Section 2.2.5 (Special Topics).

The following further presents details of the Space Shuttle ground operations and flight preparation using ShuttleSim as a backdrop since it provides the mechanism for assessing the Shuttle's current state of activities. This is a collaborative effort between NASA Kennedy Space Center (KSC) and the University of Central Florida[i].

[i] Macro-Level Simulation Model of Space Shuttle Processing, Martin Steele

Twenty-seven processes have been associated with the Space Shuttle's Mission Processing, Table 5 Shuttle Mission Processes. These follow the Shuttle's processing from pre-launch, launch, and post launch, graphically shown in Figure 1.

Table 5 Shuttle Mission Processes

Process	Location
1. "Normal" Orbital Processing Facility (OPF) Flow	OPF
2. Vertical Assembly Building (VAB) Space Shuttle Vehicle (SSV) Flow	VAB Integration Cell
3. Pad Flow	Launch Pad
4. Launch Day	Launch Pad
5. Scrub Flow	Launch Pad
6. Ascent Phase/Intact Abort	In-Flight
7. On-Orbit Phase	Low Earth Orbit (LEO)
8. End of Mission (EOM) Day	LEO
9. Land at KSC	Shuttle Landing Facility (SLF)
10. Land at Dryden Flight Research Center (DFRC)	Edwards AFB, CA
11. Land at Transoceanic Abort Landing (TAL) Site	Spain or Africa
12. Mobile Launcher Platform (MLP) Life	Launch Pad, MLP Park Site, VAB
13. Solid Rocket Booster (SRB) Retrieval	Atlantic Ocean
14. Solid Rocket Motor (SRM)/SRB Disassembly & Inspection	Hanger AF
15. Reusable Solid Rocket Motor (RSRM) Off-Site Turnaround Cycle	Utah Railroads
16. Rail RSRM Segments to Utah	Railroads
17. SRB Subassembly Turnaround Cycle	Assembly and Refurbishment Facility (ARF)
18. Rotation, Processing & Surge Facility (RPSF) Operations	RPSF
19. SRB/SRM Tracking	VAB Integration Cell
20. External Tank (ET) Manufacturing	Michoud, LA
21. ET Transport to KSC	LA to FL
22. ET Checkout	Checkout Cell
23. ET Mate & Closeouts	VAB Integration Cell
24. Space Shuttle Main Engine (SSME) Turnaround	OPF, VAB, Pad, Engine Shop
25. Orbital Maneuvering System (OMS) Pods & Forward Reaction Control System (FRCS) Cont Turnaround	Hypergolic Maintenance Facility (HMF)
26. OMS Pods & FRCS OMDP Flows	HMF
27. Orbiter OMDP	OPF, Palmdale

There are approximately 300 parts or Line Replaceable Units (LRUs) that are evaluated for complete replacement after each shuttle mission. These parts are a mix of items including valves, regulators, and actuators. The Space Shuttle Main Engines (SSME) are refurbished after each mission, and the various components comprising the Thermal Protection System (TPS), most notably the heat-resistant tiles that cover the underside of the orbiter, are evaluated and replaced as needed.

The LRU replacements and refurbishments of the SSMEs and TPS allow the STS to have a reliability quoted at >. 98 for loss of vehicle since the Challenger accident. “For comparison, a Shuttle with a reliability of 0.998, and with a design life per orbiter of about 100 cycles or flights, compares to airliners designed at 0.999999+ reliability (a probability of loss of life/vehicle in the 1 in a million's) and design lives for airliners in the 10's of thousands of cycles (70,000 flights not uncommon). “ [11]

The complexity and multitude of separate processes used on the Shuttle have evolved over many years. All of these processes need to be considered for the their applicability to commercial RLV systems. This is taken up in more detail in the Shuttle Lessons Learned section below.

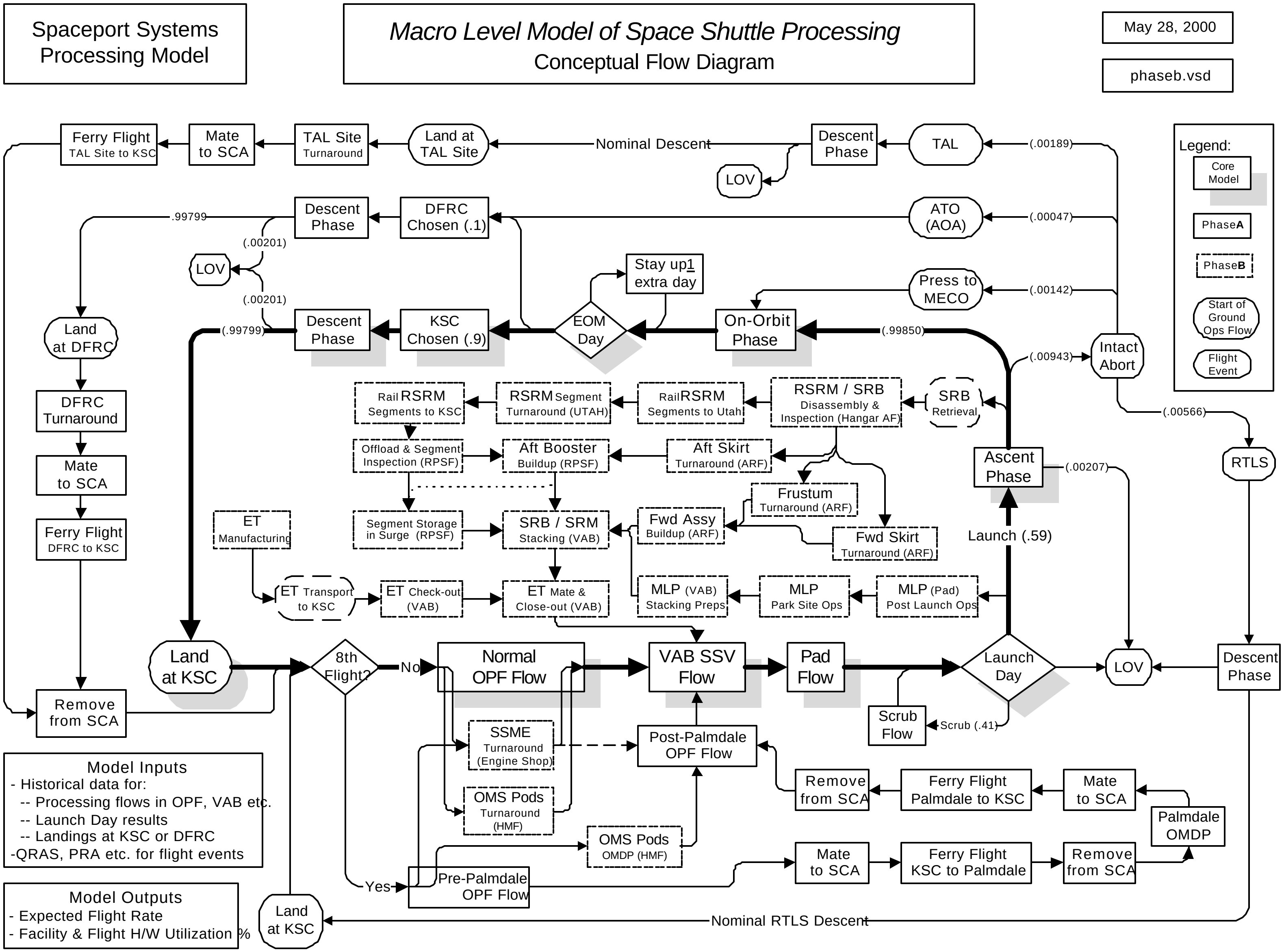

Figure 1 Flow Diagram for Space Shuttle Processing[12]

2.2.2.2 STS Procedures Review

NASA has made safety a number one attribute of the Space Shuttle program throughout its history, especially since the Challenger accident. However, the Space Shuttle is considered to be an R&D system. As such, the Space Shuttle is subject to numerous system and program checks that would be performed differently for a “fully operational system”.

There are approximately nine dependent timelines for Space Shuttle operation:

- Flight Assignment and Scheduling
- Documentation
- Safety
- Payload Integration Hardware
- Mission Planning
- Flight Products
- Technical Analysis
- Certificate of Flight Readiness
- Ground Operations

Streamlining this schedule has been a goal, but very little progress has been made in this arena. The payload preparations alone require a twenty-four month lead-time before launch. NASA’s Shuttle processing is built around a detailed timeline, a convention that has been maintained here to allow for understanding of the total scope of Shuttle O&M activities. Of key importance to this document’s discussion are the Safety, Certificate of Flight Readiness (COFR), and Ground Operations timelines.

The Shuttle Safety elements of the processing timeline associated with safety include ground safety, flight safety and hazardous materials. Both ground safety and flight safety are broken into four phases:

- Phase 0 is held during concept development. It is for aiding the payload customer. Payload safety considerations are to be developed and discussed relative to flight and mission safety and how that affects public safety for RLVs.
- Phase I safety review is to obtain Payload Safety Review Panel/Ground Safety Review Panel (PSRP/GSRP) approval of the updated safety analysis that reflects the preliminary design and operations of the payload.
- Phase II is to obtain PRSP/GSRP approval of the updated Safety Data Package (SDP) that contains the Critical Design Review (CDR) level design and operations scenario of the payload. Phase II safety analysis identifies all hazards and hazard causes; defines and documents implementation of a means for eliminating, reducing, or controlling the risks; and documents finalized, specific safety verification and on-orbit verification/re-verification methods (test plans, analysis, and inspection requirements, etc.).

- Phase III safety review is to obtain PSRP/GSRP approval of the SDP and safety compliance data that reflects the safety verification findings. "The focus of this review is to assess safety verification testing and analysis results. "

Ground safety and flight safety activities begin approximately twenty-two months prior to Shuttle launch with Phase 0. Phase I Safety Review occurs approximately eighteen months prior to launch; Phase II Safety Review fourteen months prior to launch; and Phase III Safety Review nine months prior to launch.

At approximately seven months prior to launch the hazardous material evaluation is conducted and Verification Letter #1 is issued following Flight Safety Review III. The final hazardous material evaluation and Verification Letter #2 is performed when the material is loaded.

There are four milestone reviews and a Flight Readiness Review (FRR) that review and verify status preparing for readiness for launch and receiving the Certification of Readiness.

- The Ground Operations Review (GOR) occurs approximately thirty days before delivery of the payload to KSC. This review verifies that KSC facilities, services, personnel, and payload customer are ready to continue preparing for launch.

- The Payload Readiness Review (PRR) occurs approximately three to four months prior to launch, which is prior to payload delivery to the Orbiter Processing Facility (horizontally installed payloads) or launch pad (vertically installed payloads) for integration into the orbiter. This review certifies that the payload is ready for integration into the orbiter and ensures readiness of necessary integration hardware and engineering.

- The External Tank/Solid Rocket Booster (ET/SRB) Mate Milestone Review is conducted prior to the mating operations at approximately two to three months prior to launch. Projects provide a status of the issues identified in the preparation of External Tank (ET), Reusable Solid Rocket Motor (RSRM) segments, Solid Rocket Booster assemblies and kits, and Mobile Launcher Platform (MLP).

- The Orbiter Readiness Review (ORR) occurs approximately one month prior to launch and it precedes the orbiter rollout from OPF. A status is provided of ET preparations, necessary payload accommodation hardware and payloads integration, and a schedule of planned work necessary for moving the Orbiter to the Vehicle Assembly Building (VAB) for mating with the ET and SRBs.

The FRR is conducted approximately two weeks prior to launch. It is a comprehensive review of all activities/elements necessary for the safe and successful conduct of all operations from pre-launch through post–landing and recovery operations. A signed Certification of Flight Readiness (COFR) certifies that all flight preparation processes have been successfully completed.

NASA develops and maintains the Space Shuttle Operations and Maintenance Requirements Specification Document[ii] (OMRSD) that outlines all the O&M tasks required for the Shuttle. These are broken into several functional areas from Leak Checks to Weight and Center of Gravity checks. These are documented in detail in the OMRSD. These master documents list the specific requirements for Shuttle processing, maintenance, repair, testing, modification and evaluation. These documents list the specifications, tests and tolerances for components and procedures used for Shuttle processing and integration. The original contractor and the NASA centers write each of the documents.

Structure	**NASA Engineering Center**	**Original Contractor**
Orbiter:	Johnson Space Center	Rockwell
SRB:	Marshall Space Flight Center	Morton-Thiokol (booster sections) USBI (frustum & aft sections)
ET:	Marshall Space Flight Center	Lockheed-Martin
SSME:	Marshall Space Flight Center	Rocketdyne

New upgrades are being initiated by the Space Shuttle program to help ensure continued safe operations of the Space Shuttle by improving the margin of safety (see discussion in STS Lessons Learned).

There are numerous activities occurring during the Ground Operations Timeline in preparation for launch. They begin approximately seven to eight months prior to launch. These activities are categorized in five areas: payload processing, Orbiter Processing Facility (OPF) processing, Vertical Assembly Building (VAB) preparation, launch pad preparation, and the Launch Control Complex (LCC) processing.

Once the payload arrives at the Kennedy Space Center, most of the handling is done by the payload-processing group prior to installation into the orbiter, and by the Shuttle processing group during and after installation. Payload processing is performed in parallel with vehicle processing. This is done to ensure adherence to the launch schedule. A complete array of world class processing facilities, services, ground support equipment, and operations are offered to payloads for pre-launch preparations.

Shuttle processing consists of taking the Space Shuttle (orbiter, external tank and solid rocket boosters) through a sequence of comprehensive testing,

[ii] http://mplm.msfc.nasa.gov/Omrs/U024/U024_CURRENT.rtf, http://mplm.msfc.nasa.gov/Omrs/0455/0455_CURRENT.rtf

maintenance, and verifications to make it ready for the next mission. This process takes approximately three months. Launch countdown operations are controlled from the LCC. Up to four Shuttle missions can be processed at one time at various stages in the processing schedule.

The Shuttle processes and procedures have been implemented and evolved over the life of the program. While these have a general applicability from a functional standpoint to future RLVs, it should be noted that the diverse nature of each candidate RLV will have its own method and processes.

2.2.3 14 CFR Review

There are no FARs that are applicable to Space Shuttle operations or maintenance. This initial research effort did not include a review of the Title 14 parts that address NASA operations. In general, these parts are written at a much higher level than those in place for the aviation domain. Follow-on work should include a more detailed review of 14 CFR 1200 to 14 CFR 1299.

2.2.4 General Publications Reviews

2.2.4.1 NASA, Space Shuttle Independent Assessment Team (review from October through December of 1999), Report to Associate Administrator Office of Space Flight, March 2000

NASA sponsored an independent team to evaluate Space Shuttle sub-systems and maintenance practices. This team's work made assessments that were categorized in 4 potential sources of failure:

- Hardware Failures
- Software Failures
- Organizational Failures
- Human Failures

Hardware sources of problems that were identified through this review of major Shuttle systems included the following subsystems: avionics, hydraulics, hypergolics and Auxiliary Power Units (APUs), propulsion, structures, and wiring. Software failure areas included the ground and flight software validation and verification activity. Human sources of failure were investigated in the maintenance, operations, and engineering workforces. Organizational failure sources also considered process sources and included risk assessment and management, problem reporting, and the Safety and Mission Assurance function.

They identified nine issues (synopsized below) pertinent to Space Shuttle activities that were deemed necessary to address.

> **Issue 1** NASA must support the Space Shuttle Program with the resources and staffing necessary to prevent the erosion of flight-safety critical processes.

> **Issue 2** The past success of the Shuttle program does not preclude the existence of problems in processes and procedures that could be significantly improved.
> **Issue 3** The SSPs risk management strategy and methods must be commensurate with the 'one strike and you are out' environment of Shuttle operations.
> **Issue 4** SSP maintenance and operations must recognize that the Shuttle is not an "operational" vehicle in the usual meaning of the term.
> **Issue 5** The SSP should adhere to a 'fly what you test / test what you fly' methodology.
> **Issue 6** The SSP should systematically evaluate and eliminate all potential human single point failures.
> **Issue 7** The SSP should work to minimize the turbulence in the work environment and its effects on the workforce.
> **Issue 8** The size and complexity of the Shuttle system and of the NASA/contractor relationships place extreme importance on understanding, communication, and information handling.
> **Issue 9** Due to the limitations in time and resources, the SIAT could not investigate some Shuttle systems and/or processes in depth.[12]

Of note regarding this report are Issues 1 and 4. Issue 1 addresses the reduction in skilled or knowledgeable labor force for the Shuttle program. It is a concern for that the work force is being "spread thin" or "one deep" in critical areas that affect or influence flight safety. It calls attention to the erosion of skilled staff in critical areas of Shuttle operations and safety. Issue 4 is a related issue from a workforce perspective. Yet it also highlights the "test range" philosophy of the Shuttle operations and KSC range:

> Most aircraft are described as being "operational" after a very extensive flight test program involving hundreds of flights. The Space Shuttle fleet has only now achieved one hundred flights and clearly cannot be thought of as being "operational" in the usual sense. Extensive maintenance, major amounts of "touch labor" and a high degree of skill and expertise by significant numbers of technician and engineering staff will be always required to support Shuttle operations. Touch labor always creates a potential for collateral and inadvertent damage. In spite of the clear mandate from NASA that neither schedule nor cost should ever be allowed to compromise safety, the workforce has received a conflicting message due to the emphasis on achieving cost and staff reductions, and the pressures placed on increasing scheduled flights as a result of the International Space Station (ISS). Findings of concern to the SIAT include: the increase in standard repairs and fair wear and tear allowances; the use of technician and engineering "pools" rather than specialties; a potential complacency

> in problem reporting and investigation; and the move toward structural repair manuals as used in the airline industry that allow technicians to decide and implement repairs without engineering oversight.[13]

While the Space Shuttle has achieved a flight success of 100 plus launches, the vehicle (orbiter, tanks, and solids) and program have not undergone, nor will they undergo, a Federal Aviation Administration certification program. This is due, in part, to the range operations rather than shuttle operations. The later half of the above excerpt provides a means to overcome this for the Shuttle program and may provide a potential benefit for future RLVs.

Technical Area Assessment of O&M

Additionally, key technical areas examined and reported on are as follows:

- Avionics
- Human Factors
- Hydraulics
- Hypergolics and Auxiliary Power Unit
- Problem Reporting & Tracking Process
- Propulsion
- Risk Assessment & Management
- Safety and Mission Assurance
- Software
- Structures
- Wiring

While all these play a role in the safety and mission success of the Shuttle, safety and mission assurance is of particular interest to the development of commercial RLV requirements and guidelines. The assessment team found a deficiency in procedures and processes for risk assessment and mitigation. They call for the necessity of experienced and well-staffed NASA quality assurance function and an independent NASA safety and mission assurance function.

Of the nine issues identified by SIAT (see Section 2.2.4), the following have bearing on this effort and provide lessons learned for the commercial RLV industry:

a. System redundancy should not be the primary risk management strategy. Risk understanding, minimization and avoidance must be practiced. The program must understand impacts of loss of redundancy to vehicle safety (SIAT Issue 3).
b. While "airline-like" infrastructure for maintenance and operations cannot be used for the shuttle, it must be a priority for making RLV O&M cost-effective. This may include establishment of Reliability-Centered Maintenance (RCM) approaches, similar to that used in commercial aviation (SIAT Issues 4 and 8).,

c. Configuration management must be employed to ensure that the flight configuration correlates to a known, tested configuration (SIAT Issue 5).
d. Design methodologies should preclude single points of failure, particularly those that arise from human error (SIAT Issue 6).

This report provided lessons learned for the STS program and for RLV concepts, see Section 2.2.7.

2.2.4.2 Draft Aerospaceworthiness Standards, Space Access LLC, www.spaceaccess.com

Space Access LLC developed and published a suggested set of "Aerospaceworthiness Standards (ASW)."[82] Space Access' basic approach could be applied to 2nd generation RLVs. This work was performed by Space Access LLC, and the results are available on their website. NASA funded an effort as part of SLI to have the Space Access work published. Space Access' basic approach consisted of categorizing the current aviation 14 CFR content (primarily 14 CFR 25) into three categories as they relate to safety. These categories include rules directed at preventing failures, recovering from failures, and limiting collateral damage when recovery is not possible.

RTI's assessment of the Space Access work indicates that the effort, while well intended, is somewhat superficial, and fails to fully consider the complexity of issues facing commercial RLVs. The result of the Space Access approach appears detrimental to the RLV industry, particularly to smaller companies. There is one element of the Space Access' work that warrants further study. Their analysis of the 14 CFRs highlighted a number of technical issues, identified as "Key RLV Issues" (see Table 6, Space Access LLC Key RLV Issues) that are not addressed in the aviation domain. While some of these issues may be combined, the list represents the first clear assessment of those items that will require completely new requirements or guidelines to be developed. RTI intends to validate the contents of this list as this research effort proceeds with the intent of identifying corresponding material that should be incorporated in the RLV O&M NPRM.

Table 6 Space Access LLC Key RLV Issues

Issues	Description
Atmospheric Conditions	Spatial variations in the atmosphere (e.g., windshear, density variation)
Remotely Operated Aerospacecraft	No corresponding 14 CFR treatment of Unmanned Aerial Vehicles UAVs)
Cryogenic Propellants	High energy to mass fuels typically used in rocket engines, extremely cold temperature complicating operations due to venting and boil off among others.
Venting	Mechanism for equalizing pressure inside and outside the vehicle as the vehicle rises in the atmosphere and the corresponding pressure is reduced or the pressure reduction in order to limit pressure in a cryogenic tank from propellant boil-off
Staging	Dividing the craft into multiple sections, only a portion of which remain with the vehicle throughout the remainder of its flight; used to reduce the total mass that must be lifted to achieve orbit
Outgassing	Process whereby certain materials breakdown and are converted to gases in the presence of low atmospheric pressure thus leaving the object
Micrometeoroids and Orbital Debris Damage	High velocity objects in orbit, either naturally occurring or man-made, that can damage spacecraft
Radiation	Elevated and different types of radiation than those typically experienced by conventional aircraft
Solar Heating	Effects of large temperature swings associated with operations in and out of the Earth's shadow
Atomic Oxygen	Erosive gas found in Earth orbit that causes erosion on spacecraft surfaces
Microgravity	The condition of "free fall" that exists while in orbit or in an unpowered, suborbital, parabolic trajectory.
Deorbit	Process involving precise navigational calculations and corresponding maneuvers to allow for proper trajectory through the atmosphere and arrival at the landing site
Hazardous Materials	Carriage of hazardous materials is generally a requirement for spacecraft due to the types of propulsion and environmental support required
Reentry	Separated by Space Access for specific treatment of loading, spacecraft control, and loss of communication
Fuel Reserves	Typically required of standard aircraft, fuel reserves carry a substantial weight penalty for spacecraft, and may pose unique safety issues.

Issues	Description
Engine Inoperative Capability	Typically required of standard aircraft, this type of Operation must be examined in detail for RLVs
Balked Landings and Missed Approaches	Need to consider these types of aviation requirements in light of typical RLV flight profiles, and in conjunction with the prior to issues in this list
Noise: Takeoff and Sonic Boom	More extensive problem for RLVs than current limited aviation experience, particularly when inland launch facilities are considered
Powered Lift (Vertical Takeoff and Landing)	No corresponding aviation 14 CFR treatment of this flight phase
Aerospacecraft Powerplants	No corresponding aviation 14 CFR treatment of scramjets, rocket engines, and reactive control thrusters
Fatigue Evaluation	Aging aircraft 14 CFRs and corresponding guidance does not include space flight regime and associated effects of launch/reentry loading

2.2.4.3 Identifying STS Cost and Cycle Time Design Root Causes, briefing for the SLI Architecture Working Group Meeting at NASA KSC on August 21, 2002[14]

While this addresses both cost and cycle time, only cycle time as it applies to O&M and public safety are summarized.

The purpose of the root cause work is to conduct function by function a review of STS ground turnaround processing work. This is done in order to discover technical/design root causes that have the potential of being acted upon through technical means. One question asked of the Shuttle program is why the process takes so long. The response in regards to operation work is concerned with the interactions between flight and ground assets (people, equipment, materials, etc.) needed to achieve a safe Shuttle flight. This is measured primarily with task durations.

It was uncovered that the majority of the time spent in the Orbiter Processing Facility (OPF) are in four main areas: Structures/mechanics/Vehicle handling (26% of time), Propulsion (18%), Power management systems (16%), and Thermal management system (16%). Within each area, time was spent in three actions: unplanned testing and repair (29% of time on function), vehicle servicing (26%) and inspections and checkout (24%). The unplanned testing and repair drives the lack of confidence in the hardware dependability. Vehicle servicing is intrusive and time consuming with GSE intensive work. Inspections and checkout overcomes the lack of confidence and is used to obtain certification for flight. On average about 300 Line Replacement Units (LRUs) are replaced on each mission. This average is 100 per mission if the SSMEs and TPS are not included.

The question was asked when should NASA address operations and maintenance requirements. The Shuttle Operations and Maintenance Requirements Specification (OMRS) emerged at the conclusion of the Orbiter vehicle design definition and prior to flight test. The OMRS has been essentially frozen ever since, because the O&M requirements must respond to the nature of the design. This design has not significantly changed. It is concluded that continually delaying O&M requirements to the next program phase should no longer be tolerated.

This work has concluded that there is a need for balancing reliability and safety with maintainability. The Space Propulsion Synergy Team (SPST) is currently exploring the balance between Mission Reliability/Safety with Maintainability through Poisson's Process and other academic methods. This activity should be followed and incorporated in future work for this RLV O&M effort. This team and its research may be a key liaison to this rulemaking effort.

2.2.4.4 Use of System Safety Risk Assessments for the Space Shuttle Reusable Solid Rocket Motor, Journal of System Safety Vol 38, No 1 2002[15]

After the Challenger accident in 1986 and subsequent investigations, the Solid Rocket Motors (SRMs) were redesigned. This redesign involved the tasks of identifying, understanding, and controlling risk for the new SRM. It began with hand drawn concepts, through trade studies, and fault tree analyses. To establish a baseline risk for the new SRMs several tools were developed and used: Fault Tree Analysis, Hazard Analysis, Failure Modes and Effects Analyses/Critical Items List (FMEA/CIL) and the Certificate of Qualification.

With all new changes a System Safety Assessment Sheet must now be completed. It outlines five questions: Does the change:

- Introduce any new hazards/failure modes or hazard causes/failure causes?
- Eliminate, adversely affect or invalidate any hazard controls, verification data or Critical Items List (CIL) retention rationale?
- Reduce a margin of safety for any RSRM component?
- Change the criticality category assignment?
- Require an adverse (increase in severity or in probability) change to the NSTS 22254 risk matrix classification of a hazard cause? *(NSTS 22254 is the document called: "Methodology for Conduct of Space Shuttle Program Hazards Analyses, Requirements for Preparation and Approval of Failure Modes and Effects Analyses (FMEA) and Critical Items List (CIL)."*

If any of these are answered yes then a risk change Document Change Notice (DCN) to the baseline Hazard Report and or FMEA/CIL may be required. Hazard risk analysis consists of identifying the likelihood versus the severity of the risk. There are three risk classifications:

- Unacceptable Risk – Hazard for which corrective action must be taken prior to flight.
- Acceptable Risk – Hazard that requires program evaluation and acceptance of control limitations and uncertainties.
- Controlled Risk – Hazard where appropriate controls have been implemented and comply with program requirements.

Each cause is assessed for likelihood:

- Probable: expected to happen in the life of the program
- Infrequent: Could happen in the life of the program; controls have significant limitations or uncertainties
- Remote: Could happen in the life of the program, but not expected; controls have minor limitations or uncertainties
- Improbable: Extremely remote possibility that it will happen in the life of the program; strong controls in place.

The RSRM FMEA/CIL identifies three failure criticality (Crit) levels:

- Crit 1 – Single failure that could result in loss of life or vehicle
- Crit 1R – Redundant hardware items(s), all of which, if failure occurs, could cause loss of life or vehicle
- Crit 3 – All others

This all leads to the Certificate of Qualification (COQ) to assess risk. The COQ offers certification and qualification that the design of the RSRM meets Contract End Item (CEI) specification requirements.

While most if any RLV concepts do not require reusable solid motors, the process highlighted in this paper may have applicability for other aspects of the RLV O&M. This specifically touches on the certification issue for RLVs. More specifically this approach may lend itself to the development of a set of guidelines.

2.2.4.5 Streamlining Space Launch Range Safety, National Research Council

This document prepared for the US Air Force(AF). The task statement specified three areas to be investigated:

- Top-level, independent review of the Air Force's safety guidelines and procedures for government and commercial space launches as published in Eastern and Western Range Safety Requirements (EWR) 127-1 to determine if there are alternative approaches to the protection of the general public that are both more efficient and less expensive
- An independent assessment of the current and planned range safety and flight termination systems and procedures for government and commercial space launches to estimate the technical feasibility as well as the cost effectiveness of an autonomous Global Positioning System (GPS) flight termination system

- An independent examination of the AF's safety guidelines and procedures associated with incursions of aircraft and ships into restricted air space and waters to determine if holds and delays of government and commercial space launches can be reduced while still maintaining an acceptable level of safety

While investigating risk criteria, risk management, and analysis methods it was uncovered that the Casualty Expectation, E_C, of $30x10^{-6}$ is equivalent to a rate of one casualty every 1,000 years, or $1x10^{-3}$ casualties per year, given an average launch rate of 33 per year. An E_C of $30x10^{-6}$ is also comparable to the risk accepted by the public for commercial air travel. This is reported to be supported by the finding, from 1982 through 1998, US air carriers had 131 million departures, and accidents resulted in 2,868 casualties (354 serious injuries and 2,514 fatalities), which is equivalent to an E_C, of $22x10^{-6}$ per departure (NTSB, 2000, Tables 3 and 5, see Section 3.7.5.1.2). Additionally, it was found that a collective risk standard, E_C, of $30x10^{-6}$ is consistent with the risk standards of many other fields in which the public is involuntarily exposed to risk. Using E_C two probability parameters are calculated for use in determining the safety of the range, Probability of Casualty (P_C) and Probability of Impact (P_i)

This report contends the same basic safety criteria for RLVs should be the same as that for expendable launch vehicles in terms of E_C, P_C, and P_i. Further, range safety processes for RLVs will require special attention because RLV concepts vary in design and operational characteristics. Additionally, RLVs carrying humans require additional safety of flight issues, especially considering autonomous or semiautonomous Flight Termination Systems (FTSs). This work did not develop specific means of compliance for new classes of RLVs because they felt it will vary with the design of each vehicle.

2.2.4.6 Lessons Learned From Challenger, HQ NASA Safety Division Office of Safety, Reliability, Maintainability and Quality Assurance, Washington DC, February 1988

There are numerous lessons learned that came out of the findings from the Challenger accident in 1986. Headquarters NASA Safety Division released a succinct report on the collective lessons learned from various investigating teams. Of these findings the following provides a presentation of the findings of STS O&M relevant to future RLVs[16]

When reviewing Shuttle program processes a safety risk management problem was identified. The policies, criteria, requirements, and management systems were not adequate to assure complete review and assessment of safety risks. The causes were identified as: changed safety risk management policies, criteria, and requirements and decentralized safety functions; headquarters safety management structure changed during Shuttle development and operations phases; changes confused field centers and contractors efforts to follow and repeat the changes in basic safety policy; system safety procurement directives fluctuated several times in 15 years prior to Challenger's flight 51-L and contributed to the de-emphasis of safety among others.

Additionally, it was determined that there was inadequate definition and tracking in the problem resolution process, corrective action, risk assessment, and assurance management for some flight critical components. Causes include critical assessments in error such as the O-rings being assessed as a critical category then reclassified possibly causing confusion and closing of the erroneous problem. Another cause is linked to the assessment by in-line workers dependent on the program for immediate future career having major impacts to budget and schedule. Additionally, trend analysis was inadequate; Flight Readiness Reviews discourage flagging repetitive problems; there were inconsistent critical problem handling such as on the SSME; and lack of critical component qualification data.

A degradation of the Flight Readiness Review (FRR) Process occurred during this period. Causes that were attributed to this include:

- Flight Readiness Review procedures were ignored.
- FRRs had been reduced in importance seen by reviews conducted telephonically with incomplete attendance of key personnel.
- Additionally, there was a failure to communicate critical concerns and teleconference data was not recorded resulting in the launch of 51-L.

While investigating crew safety issues it was discovered that there were no crew escape options available during Shuttle first stage operation. There were management decisions to exclude crew escape options during the first stage operation. This was considered several times during the program but was rejected despite the fact that first stage operations is the most dangerous. Some technically feasible solutions were undesirable because of risk that would have been introduced to the program was potentially greater than having no abort capability. Implementation of feasible, desirable options would have further delayed the first Shuttle flight which was already behind its original schedule.

Qualification, certification, and other test specifications for some flight critical components were not properly defined. This stemmed from inadequate performance and verification specifications; and were not assured required performance with an acceptable margin of safety. Specifically, the O-ring specification did not contain realistic performance or temperature requirements. The interaction between systems was not thoroughly assessed for impacts to the system, component, or part specifications as the total integration of the Shuttle occurred.

It was found that not all critical processes were formally identified and controlled. This stemmed form NASA lacking control of some critical processes. Because the original O-ring putty contained asbestos, it was necessary to procure a new putty when the original supplier stopped production. The performance of the new putty was highly unpredictable. It was proprietary and therefore no control over the process occurred. The O-ring material itself was unknown since it was proprietary. Because there was no control over the proprietary components, changes to these materials could be made without certification and approval.

It was found that the compliance with the operations and maintenance documentation was inadequate for some flight critical systems. This stemmed from two causes: first, there were errors in the technical operating procedures and second, there were improper deviations from approved technical operating procedures.

While there were numerous other problems uncovered in these investigations, those presented provide some guidance to commercial RLV O&M activities. The lessons learned from these are summarized in Section 2.2.7 Shuttle Lessons-Learned.

2.2.5 Special Topics

2.2.5.1 Simulation

Simulation is used extensively for modeling shuttle operations. One such simulation is called ShuttleSim. The ShuttleSim tool is a macro level simulation model for the Kennedy Space Center (KSC) Shuttle operations. This model serves as a test bed for various improvement strategies to reduce the cost of operations, meet schedules, improve safety, and increase supportability. The model is used to answer questions regarding the effect of various parameters such as the Orbiter Processing Facility (OPF), Vehicle Assembly Building (VAB), Mobile Launcher Platforms (MLP), and launch pad processing times and the number of orbiters, OPFs, VABs, Launch Pads, etc., on the expected flight rate and the utilization of each facility. In addition, the model will be used to make recommendations on how to achieve higher flight rates per year.

This is a probabilistic simulation model of the operational lifecycle of the STS flight hardware elements processing through their respective ground facilities at the Kennedy Space Center (KSC). Processing flow is dependent upon the flight hardware's return to KSC following the mission, therefore flight operations of the ascent, mission duration, and landing phases were also modeled.

"Simulation was chosen as a tool for modeling the space shuttle flight hardware processing lifecycle for several reasons. First, because of the inherent complexities of spaceport operations, analytical modeling techniques often fail to capture the behavior of such systems. For example, mathematical programming models cannot estimate the work-in-process nor can they model such occurrences as equipment breakdowns. Simulation is often the only tool available for modeling these complex systems. Moreover, simulation modeling allows the representation of complex systems consisting of hundreds of deterministic and stochastic elements, which are elaborately related with each other. Finally, the simulation model can be used to perform sensitivity analysis on the system and answer “What-if” type of questions concerning the influence of input parameters (e.g., the number of launch pads) on the output measures of performance (e.g., maximum flight rate and facility bottlenecks) all without disturbing the actual system (Mollaghasemi *et al.* 1998).” [17]

While not fully developed for reliability and O&M practices, this tool may have value for the RLV industry in O&M processes. A key element to be added to this model is the system reliability role up capability. This would generate a probability of failure for each subsystem as well as an overall failure probability used for calculating Casualty Expectations, E_C.

2.2.5.2 Space Launch Initiative

The Space Launch Initiative (SLI) is the term used by NASA to describe a diverse set of technology demonstration and development programs currently underway at various NASA, DoD, university, and private firms designed to open the space frontier for continued civil exploration and commercial development. It is synonymous with the 2nd Generation Reusable Launch Vehicle Program.

NASA’s strategic goals for a next generation RLV are to reduce the risk of crew loss to approximately 1 in 10,000 missions from 1 in 250 and to lower the cost of delivering payloads to low-earth orbit to less than $1,000 per pound. NASA has committed $4.85 billion for risk reduction and technology development efforts to be expended over the period of FY 2001 through FY 2006. NASA hopes to develop at least two competing architectures, and in so doing, reduce the technical, cost, and business risks to acceptable levels to enable full-scale development of a 2nd Generation RLV around the middle of the decade. A new system could be operational early in the next decade.

2.2.6 Interview Summary

Several interviews have been conducted to date associated with the Space Shuttle. The following is a summary of interviews conducted in-person at Kennedy Space Center. Note: each of the individuals interviewed was given the opportunity to review and correct/amend the notes taken during the interview. Details of each interview are contained in Appendix E.

Please note: The following extracts are taken directly from the interviews conducted. Editing has been minimized to ensure the interviewee's original intent is maintained. Lessons learned constructed from these interviews can be found in Section 2.2.7. The interview responses reflect the perspectives of the individual or their organizations.

2.2.6.1 NASA 1: Shuttle Systems Engineering

There were three key issues that came from this interview.

1. FAA and NASA should be collaborating on test criteria (specifically what and when to test, as opposed to how to test).

2. It is probably premature to think in terms of Minimum Equipment List (MEL) since there is insufficient reliability data to support it.
3. The safety factor for the Shuttle (1.4) is lower than the typical level for commercial aircraft. This does not allow for any margin which in turn demands a higher level of testing.

2.2.6.2 NASA 2: Shuttle Processing Modeling

The key facts emerging from this interview include:

1. The Shuttle processing flow is broken into phases of flight with 26 processes involved throughout the processing flow.
2. Although built for Shuttle, ShuttleSim was modified for a Generic RLV. It is a flexible and modifiable tool, Figure 2, Generic RLV Flow.
3. Inputs to validate the model came from numerous data sources from NASA KSC.

2.2.6.3 NASA 3: Contractor

1. Advanced Spaceport Technology Working Group (ASTWG) adopted Vision Spaceport Program (VSP).
    a. The ASTWG broke out humans from payloads
2. KSC uses PRACA (Problem Reporting and Corrective Action) database for all problem reporting.
3. There is a need for a Ground System Technology development for turn-around improvement.
    a. The last development was in ‘50s with the Atlas ICBM refueling requirement to fuel as it rises out of silo.
    b. There are no new rapid fueling requirements.
    c. Atlas V uses new approach for safety and fewer moving parts.
        i) Uses pressure not pumps
        ii) Reduces parts count

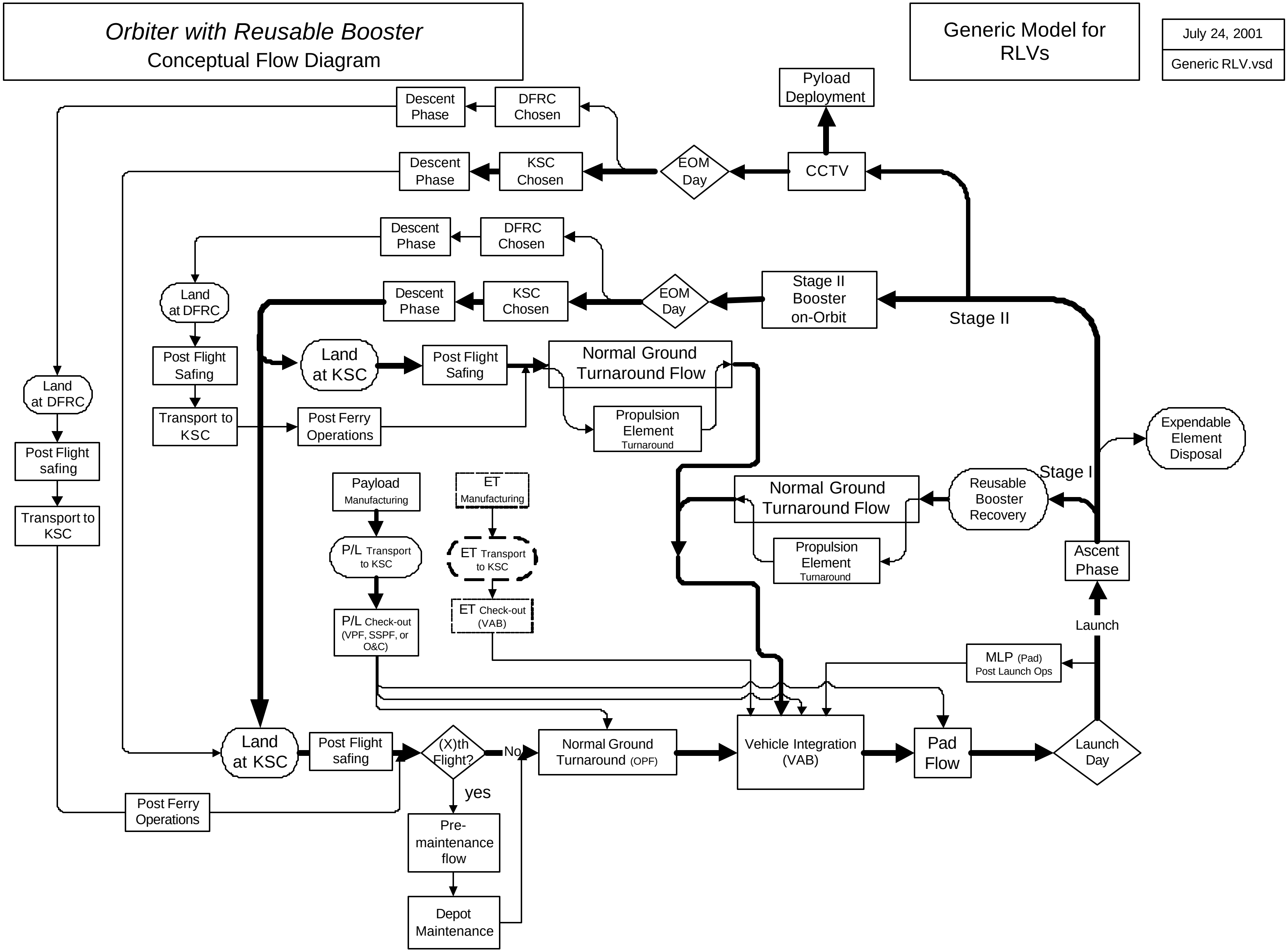

Figure 2 Generic RLV Flow

2.2.7 Shuttle Lessons-Learned

There were numerous lessons learned extracted from the publications review and interview process for STS. While many of these lessons relate to business or non-safety considerations, each should be reviewed for inclusion in regulation or accompanying guidance. These are summarized and categorized below. In addition, a numbering scheme has been introduced to identify each lesson within these groups. These numbers are used in Table 15 to correlate the lessons learned with both the system functions and procedural items (discussed in more detail in Section 3.6). Additional numbers have been reserved to be used in later phases of this research effort.

2.2.7.1 Rulemaking Issues [STS1 – STS100]

Licensing has higher costs due to minimal repeatability or reliability, while certification appears cheaper. [STS1]

Operations transition must be defined clearly. The operational status of high-technology, complex aerospace systems must be carefully defined, planned and implemented to assure that any “residual R&D nature” of the system is considered and that adequate time and resources are made available for transition.[STS2]

Specific transition criteria must be established. Systems and programs must have specific criteria established, reviewed, approved, and maintained for achieving operational status. (It should be noted that this requirement is applicable to commercial operations. Commercial operational status will be inherently different and not be confused with NASA-operational status.)[STS3]

Most aircraft are considered "operational" after very extensive flight testing of hundreds of flights. The Space Shuttle now has only 100 flights and clearly cannot be termed "operational" in the conventional aviation sense.[STS4]

There is a need for balancing reliability and safety with maintainability. The Space Propulsion Synergy Team (SPST) is currently exploring the balance between Mission Reliability/Safety with Maintainability through Poisson’s Process and other academic methods. This activity should be followed and incorporated in future work for this RLV O&M effort.[STS5]

[STS6-STS100 Reserved]

2.2.7.2 Program Processes [STS101 – STS200]

Standard program-wide requirements, definitions and procedures are needed. STS program wide procedures for both hardware and software must have a minimal approval authority. Additionally, it should include concurrences for risk and criticality identification, change, acceptance, elimination and closure.[STS101]

Complete and independent critical problem assessment are needed. Disposition of critical problems must not be made until an independent assessment is conducted.[STS102]

Complete and accurate trend data are needed for problem resolution. Care must be used to prevent the use of erroneous or out-of-date data in solutions.[STS103]

Priority consideration for critical problem resolution is required. Criticality ground rules, management requirements, and criteria for analysis must be rigidly adhered to.[STS104]

Complete and accurate qualification data are needed.[STS105]

The flight readiness review process must be maintained. FRRs must include assurance that all previous operational anomalies have been reviewed and properly dispositioned.[STS106]

Clear and accurate communications are vital. All critical concerns must be fully communicated to all personnel to all appropriate levels of management so that critical decisions can be made based on complete information.[STS107]

Control of Critical processes are required. A highly disciplined review mechanism must be maintained to ensure that the process of identifying and controlling critical processes is effective.[STS108]

Review and verification is essential. Materials whose characteristics and fabrication are not well understood must not only be tested and certified, but must undergo an independent review before approval.[STS109]

Change control is required. Changes to critical materials must be considered new and undergo adequate retesting and certification including the approval process.[STS110]

Monitoring and control of critical operations are required. Where it was determined that the safety risks or the downtime necessary to replace or repair the systems were no longer acceptable, redundant systems must be installed.STS111]

Parallel processing for vehicle elements should be done to minimize turnaround times.[STS112]

The top 4 potential sources of failure are hardware failures, software failures, organizational failures, and human failures.[STS113]

[STS114-STS200 Reserved]

2.2.7.3 Safety [STS201- STS300]

The STS program has good decomposition and coordination of subsystems; however, NASA concedes that their integration has not been accomplished as well as it probably could have been. While this would appear to be a system (design) engineering issue, stovepipe manufacturing leads to tremendous duplication, and therefore, a greater number of failure modes. [STS201]

System redundancy should not be the primary risk management strategy. Risk understanding, minimization and avoidance must be practiced. For the Shuttle, a move towards "airline-like" infrastructure for maintenance and operations should not be used. Moving towards "wear and tear allowances", engineering pools instead of specialists, complacency towards incidents, use of repair manuals that allow technicians to repair without engineering oversight is not working. SIAT's opinion was that these specifications may have contributed to relaxed standards by the technicians, quality assurance and engineering personnel. Additionally, their view is the Space Shuttle should follow "fly what you test/test what you fly" methodology. The Space shuttle program should evaluate and eliminate all potential human single point failures.[STS202]

Safety risk management policies, criteria requirements, and structure must be maintained. A periodic review and update of the entire safety risk assessment capability must be performed including skills, staffing and systems.[STS203]

System safety procurement emphasis must be maintained. Safety Division of NASA HQ must ensure contractors receive and are provided resources to support independent safety risk assessment in accordance with current policy.[STS204]

Effective safety risk assessment process must be maintained. [STS205]

Tracking and verification of hazard controls must be maintained. This must include a review and revalidation of the original hazards controls and a reverification that controls are maintained.[STS206]

Crew safety is critical to program success. Requirements concepts and implementation planning for manned flight programs must provide for adequate crew safety in emergency situations, including early detection and either avoidance, safe haven mode(s), escape or rescue.[STS207]

Crew safety early planning is a must. Requirements implementation and plans must be established early in manned-flight programs to preclude later schedule and funding impacts that prove to be unfeasible.[STS208]

Crew safety assurance is required. There must be in place periodic reviews over the life of the program to assure that adequate crew safety planning and implementation is maintained.[STS209]

E_C of $30x10^{-6}$ is comparable to the risk accepted by the public for commercial air travel (from 1982 through 1998, US air carriers had 131 million departures, and accidents resulted in 2,868 casualties (354 serious injuries and 2,514 fatalities), which is equivalent to an E_C, of $22x10^{-6}$ per departure (NTSB, 2000, Tables 3 and 5)).[STS210]

Collective risk standard, E_C, of $30x10^{-6}$ is consistent with the risk standards of many other fields in which the public is involuntarily exposed to risk.[STS211]

ShuttleSim and similar Shuttle modeling tools may have value for the RLV industry in O&M processes for establishing a system reliability role up capability. This would generate a probability of failure for each subsystem as well as an overall failure probability used for calculating Casualty Expectations, E_C.[STS212]

[STS213-STS300 Reserved]

2.2.7.4 Design and Technology [STS301 – STS400]

Technology will enable the robustness required for certification of RLV vehicles. The two critical technology areas are propulsion and structure materials. These two will enable a Safety Factor commensurate with the O&M activities that are similar to the aviation industry. [STS301]

The Shuttle safety factor provides no margin for the robustness required of certification, while O&M metrics can be known to the exact value due to voluminous testing. As noted, the safety factor used on the shuttle is about 1.4. Aircraft operate with a margin of two or greater. Guidance for what the appropriate safety factor to design to and operate to may be required. Technology will need to evolve to meet these requirements.[STS302]

The number of Shuttle launches is too few to have confidence in components. Therefore, extensive testing is conducted to build the confidence and establish reliabilities. [STS303]

It has been noted that the STS technology, though thirty years old, is not mature. Additionally, some of the testing is intrusive; therefore wear associated with testing must be considered in the Shuttle model. This is seldom the case for aircraft. [STS304]

It has been noted that the Shuttle was built before there was a mission for the transportation it provides, namely the Space Station. STS is the transport for Station. There was a decision to build STS first, before the Space Station. This made it difficult to focus on requirements. STS should have been a people carrier while for space lift since we had the Saturn and other launch capability. This lead to a prediction of flights in the '70s as late as '77 & '78 to have 48 KSC Shuttle flights projected and 12 Vandenberg launches.[STS305]

Comprehensive performance, process, & material specifications are needed. Every acceptable performance or material specification must contain provisions for assuring that the performance or material will satisfy all required conditions.[STS306]

Critical items must be fully qualified by testing or other means. New materials and new designs must require thorough testing to determine all technical characteristics, environmental effects, stress margins, and failure rates prior to introduction into critical use.[STS307]

Proprietary product specifications must be adequate. The use of such products should be avoided where no data is available.[STS308]

Interactions between systems need to be defined, verified, and validated. As designs approach the critical design review point, the systems engineering function for the program integrator must review all potential physical and functional interactions possible between systems, equipment, and facilities, and initiate updating of the affected specifications.[STS309]

Design methodologies should preclude single points of failure, particularly those that arise from human error (SIAT Issue 6).[STS310]

[STS311-STS400 Reserved]

2.2.7.5 Maintenance and Operations [STS401 – STS500]

Comprehensive qualification testing is needed. Qualification testing on all systems over the full range of possible environments shall be conducted.[STS401]

When qualification testing does not duplicate the actual operational environment, extensive analysis must be performed before an item or system is certified. It should be noted that this certification is referring to NASA component certification not FAA certification.[STS402]

Operations and Maintenance Document (OMD) requirements review and update is necessary. Safety must approve all Operations and Maintenance Instructions (OMI) containing critical and hazardous operations.[STS403]

OMD compliance is essential. All critical requirements, regardless of source, must be readily traceable through to compliance or non-compliance.[STS404]

Shuttle maintenance and operations must recognize that the Shuttle is not an "operational" vehicle in the usual meaning of the term.[STS405]

The Shuttle program should systematically evaluate and eliminate all potential human single point failures.[STS406]

It is a concern for that the work force is being "spread thin" or "one deep" in critical areas that affect or influence flight safety. It calls attention to the erosion of skilled staff in critical areas of Shuttle operations and safety.[STS407]

Findings of concern to the SIAT include: the increase in standard repairs and fair wear and tear allowances; the use of technician and engineering "pools" rather than specialties; a potential complacency in problem reporting and investigation; and the move toward structural repair manuals as used in the airline industry that allow technicians to decide and implement repairs without engineering oversight.[4][STS408]

While "airline-like" infrastructure for maintenance and operations cannot be used for the shuttle, it must be a priority for making RLV O&M cost-effective. This may include establishment of Reliability-Centered Maintenance (RCM) approaches, similar to that used in commercial aviation (SIAT Issues 4 and 8).[STS409]

Shuttle operation work takes so long due to the interactions between flight and ground assets (people, equipment, materials, etc.) needed to achieve a safe Shuttle flight.[STS410]

It was uncovered that the majority of the time spent in the Orbiter Processing Facility (OPF) are in four main areas: Structures/mechanics/Vehicle handling (26% of time), Propulsion (18%), Power management systems(16%), and Thermal management system (16%).[STS411]

Time was spent in three actions: unplanned testing and repair (29% of time on function), vehicle servicing (26%) and inspections and checkout (24%). The unplanned testing and repair drives the lack of confidence in the hardware dependability.[STS412]

Vehicle servicing is intrusive and time consuming with GSE intensive work. Inspections and checkout overcomes the lack of confidence and is used to obtain certification for flight. On average about 300 Line Replacement Units (LRUs) are replaced on each mission.[STS413]

The question is asked when should NASA address operations and maintenance requirements. The Shuttle Operations and Maintenance Requirements Specification (OMRS) emerged at the conclusion of the Orbiter vehicle design definition and prior to flight test. The OMRS has been essentially frozen ever since, because the O&M requirements must respond to the nature of the design. This design has not significantly changed. It is concluded that continually delaying O&M requirements to the next program phase should no longer be tolerated.[STS414]

There is a need for a Ground System Technology development for turn-around improvement for safety and fewer moving parts.[STS415]

[STS416-STS500 Reserved]

2.3 Reusable Launch Vehicles

2.3.1 Background

There is considerable variation in the RLV concepts being discussed, designed, built, and in some cases test flown, see Appendix C. Elements of traditional aircraft can be found in many of these concepts, but not all. For example, the now defunct Rotary Rocket effort relied on rotorcraft technology as a basic component in the design, primarily for descent. The current DaVinci effort in Canada relies on a balloon for its atmospheric ascent phase. In this research effort, care has been taken to survey the wide range of RLV concepts either actively being pursued or which have been postulated in the past to ensure that the resulting O&M regulations provide sufficient flexibility to accomplish their safety purpose yet not preclude technology development nor hamper global competitiveness. Numerous government programs began and failed due to funding issues. Publications and interviews for the X-33 and X-34 programs yielded several insights and lessons learned; however no sufficient data sources were found to provide information germane to this topic for X-37, X-40A, and X-43. Appendix C provides a more detailed list of current and past RLV efforts.

As a starting point, the team accomplished a review of the various FARs created to date to address commercial space activities with particular emphasis on 14 CFR 431. This 14 CFR, along with Advisory Circular (AC) 431.35-1, *Expected Casualty Calculations for Commercial Space Launch and Reentry Missions,* AC 431.35-2, *Reusable Launch and Reentry Vehicle System Safety Process*, and the recently published *FAA and Industry Guide to Reusable Launch Vehicle Operations Safety Approval*, layout the foundation for licensing an RLV. The 'safety approvals' discussed in 14 CFR 431 and the accompanying guidance may be thought of as a corollary to the type design approval used in the aviation domain. While the analogy is not perfect, is does allow for the formulation of a list of generic RLV functions that safety approvals will need to address and that follow-on O&M practices will have to ensure ongoing safe operation.

The rest of this section provides the results of the 400-series 14 CFR review along with a more detailed look at the various RLV concepts being explored today. Like the aviation and space shuttle domains, a detailed literature search was conducted and a series of interviews related to the RLV industry were conducted.

2.3.2 Current Practices

Identifying current practices for the RLV community is an interesting proposition given the wide array of RLV concepts that are being pursued and the various levels of maturity in the organizations engaged in such activities. Aside from the Space Shuttle (discussed in the last section), the majority of competing RLV designs trace their lineage to either the ballistic model (vertical takeoff via conventional launch) or the aviation model (takeoff roll, rotation, and climb). Both of these two domains is drawing heavily on the personal experience of their employees that has the effect of fostering either ballistic or aviation-related operations and maintenance processes as appropriate.

2.3.3 14 CFR Review - 400 Series

A set of detailed matrices summarizing the selected 14 CFRs, as well as capturing questions/comments relating to the 14 CFR content, were developed to provide a reference for this effort going forward. These detailed matrices may be found in Appendix D. See Section 2.1.3 for more information on the 14 CFR review process and phasing.

2.3.3.1 14 CFR 400 – Basis and Scope

This 14 CFR part contains the basis and scope for the commercial space transport regulations. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.2 14 CFR 401 – Organization and Definitions

This 14 CFR part contains organization and definitions for Commercial Space Transportation. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.3 14 CFR 404 – Regulation and Licensing Requirements

This 14 CFR part contains regulation and licensing requirements for commercial transportation. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.4 14 CFR 405 – Investigations and Enforcement

This 14 CFR part contains investigations and enforcement for launch sites, reentry sites, manufacturing, production, testing, and assembly sites belonging to primes as well as contractors in the commercial space transportation domain. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.5 14 CFR 406 – Administrative Review

This 14 CFR part contains rules establishing persons (anyone affected by a decision concerning a license) entitled to a hearing as well as rules for administrative review of the issues. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.6 14 CFR 413 – License Application Procedures

This 14 CFR part contains procedures for license for operating launch sites and reentry sites. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules.

2.3.3.7 14 CFR 415 – Launch License

This 14 CFR part contains launch license for vehicles other than RLV. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules and to ensure compatibility of the new regulations and guidance.

2.3.3.8 14 CFR 420 – License to Operate a Launch Site

This 14 CFR part contains procedures for obtaining and retaining a license to operate a launch site for the purposes of commercial space transportation. This 14 CFR was reviewed for examining if these rules were applicable and adequate for RLVs also and for avoiding any conflicts in the new proposals for rules.

2.3.3.9 14 CFR 431 – Launch and Reentry of a Reusable Launch Vehicle

This 14 CFR contains requirements for preparing and obtaining RLV mission license, and post-license responsibilities. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules and for making the new rules flow without gaps in safety.

2.3.3.10 14 CFR 433 – License to Operate Reentry site

This 14 CFR part contains requirements for obtaining and retaining a license to operate reentry site. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules and for investigating any corresponding issues for operations and maintenance activities.

2.3.3.11 14 CFR 435 – Reentry of a Reentry Vehicle Other than a RLV

This 14 CFR part contains reentry requirements for vehicles other than RLV. This 14 CFR was reviewed for avoiding any conflicts in the new proposals for rules and to ensure compatibility of the new regulations and guidance.

2.3.3.12 14 CFR 440 and 450 – Financial Responsibility

These 14 CFR parts contain requirements for financial responsibility of organizations responsible for commercial space transportation; one is for launch and another for reentry. These rules are there to ensure the financial stability of the operators so that critical safety functions in design, operation and maintenance are not neglected for economic reasons. These 14 CFRs were reviewed for avoiding any conflicts in the new proposals for rules.

2.3.4 Publications Reviews

The following publications were found to be particularly useful in highlighting the various issues associated with RLV approvals as they relate to O&M issues:

2.3.4.1 Edgar Zapata, Reusable Launch Vehicle Certification from National Aeronautics and Space Administration, Kennedy Space Center publications, August 1995, http://science.ksc.gov/shuttle/nexgen/rlvhq14.htm

The author compares NASA approaches for Space Shuttle operations and commercial airline approaches for aircraft operations. Note that this is a 1995 article; but the general philosophy is applicable. The following are the salient points made in this article:

- Aircraft-like RLV operations require that reusability be built into the design with rigorous development of system to such a degree that subsequent assemblies and productions need not require the same degree of scrutiny once a design is approved.
- RLVs should be tested and certified for high-life limits and usage, and monitored for failures. High mission reliability alone is not enough.
- Process of continued airworthiness requires that there should be non-intrusive testing of systems, minimal replacement of components, quick turnaround, and quantitative measures of safety.

2.3.4.2 Patrick Collins, The Regulatory Reform Agenda for the Era of Passenger Space Transportation, 20th International Symposium on Space Technology and Science, delivered during the conference in Gifu, Japan, May 19-25, 1996.

This publication stresses that in order to extend existing aviation regulations to apply to launch vehicles, appropriate rules concerning vehicle structural integrity and damage tolerance, fire-suppression systems, passenger evacuation standards, maintenance procedures and other matters must be developed. This article suggests regulatory innovation over a wide range of fields, as discussed in the following:

- Vehicle Certification
- Staff Training and Licensing Air Traffic Management
- Space Debris

The article also suggested the possibility of deregulation for the RLV industry. However, it acknowledged that such an approach was problematic for a number of reasons including liability, incongruity with the aviation approach, and the potential effects on public safety. The conclusion drawn from reviewing this document was further affirmation that building a set of RLV O&M rules leveraged (at least to some extent) on the current aviation regime is appropriate and expected.

2.3.4.3 Kennedy Space Center 2nd Generation Reusable Launch Vehicle Program Concept of Operations, Final Draft May 31, 2002

This document was prepared to provide the NASA Space Launch Initiative (SLI) program with a vision of a space transportation system operation. It focuses on two areas: Affordability and Safety. The focus on safety is to improve safety, measured as crew loss, to less than 1 in 10,000 missions vice the current 1 in 250 missions. This document sought to bridge the safety gap by providing a more mature understanding of what drives operations for RLVs.

Space transportation ground flow was broken into 12 functional breakouts. These all are available but may not apply to a particular concept. Each of these may be eliminated, improved, or any other change as required for the concept. Each of these functional areas are further developed with applicable concept definitions. Additionally, each functional area has a concept of operations developed for it outlining impacts to operations but also affects on maintenance activities such as reduced parts count, modularizing interfaces, etc.:

- Flight Crew/Passengers and Payload/Cargo
- Traffic & Flight Control
- System Operations
- Element Receipt and Acceptance
- Landing/Recovery
- Turnaround
- Assembly & Integration
- Launch
- Depot Maintenance
- Concept Unique Logistics
- Spaceport Infrastructure
- System Operations Planning and Management
- Community Infrastructure

This document provides a framework for RLV operations activities that may be applied to any concept and is therefore a useful starting point for functional analysis for follow-on work.

2.3.4.4 Space Tourism Act

In 2001 a bill was introduced to the House of the US Congress called the Space Tourism Act of 2001, H.R. 2443. Its purpose is to promote the development of the US space tourism industry. The essentials of the bill highlight the Findings as follow:

- We as humans have the desire
- We have the capability of safe space flight
- Nation's human space flight can be used by private sector
- Space tourism has the potential to be a significant industry
- Federal government could be key player by:
    - Guaranteed loans

- o Tax credits, expeditious establishment of a straightforward and predictable regulatory structure
- o Research and development in technologies to enable private sector to develop operational passenger carrying systems and on-orbit habitations
- o FAA-AST should have the lead role establishing regulatory structure to ensure safety of US space tourism
- o NASA should continue its traditional role of R&D related to new space technologies and systems and facilitating transfer to private sector
- o Federal Government should encourage the development of US space tourism
- o Federal Government should not compete with the private sector in the provision of transportation vehicles or facilities for space tourism

The bill also calls for the establishment of regulatory standards. These standards are to be issued not later than 2 years after enactment of this Act. The regulatory standards are to ensure safe operation of passenger carrying launch and reentry vehicles for space tourism; and for the provision of and safe operation of habitable facilities in outer space for space tourism. Additionally, the bill calls for issuance of regulations to prevent the growth of orbital debris resulting from space tourism.

While this bill does not directly call for public safety regulations or guidelines it does highlight the potential for space tourism of which RLV operations will likely play a major role. Therefore in developing the O&M performance criteria and standards in the next phase it is necessary to consider space tourism act and promotion of the industry.

2.3.4.5 Overview of Conceptual Design of Early VentureStar Configurations[18]

The X-33 was a test vehicle for technology demonstration as well as some O&M activities. The X-33's purpose was primarily two-fold. First it was to test the new aero-spike engine design and secondly to test a new metal TPS. New engine design had undergone numerous component-level tests. The first aero-spike test engine had completed 14 planned hot fire tests. It was fired more than 1,460 seconds of total operating time. This engine development cost was much less than the cost of normal standard engine development. The metallic thermal-protection system panels designed for the X-33 had passed series of high-speed, high-temperature tests in laboratories, wind tunnels and NASA research aircraft to duplicate flight conditions. More than 95 percent of the X-33's TPS panels were delivered. The panels were to reduce maintenance time and costs from the more fragile thermal tile systems.

The X-33 was more than 85 percent complete including the liquid oxygen tank, avionics bay, flight umbilicals, reaction control system thruster controller and landing gear when it was cancelled in 2001. Numerous insights were provided during the interview regarding the X-33, see 2.3.6.6.

2.3.5 Special Topics

2.3.5.1 Modeling: Vision Space Port

Vision Spaceport models operations of a generic spaceport into 12 functional modules summarized in Table 7, Spaceport Module Listing. Each module is defined and detailed in the VSP documentation called Vision Space Port Module Definition. The twelve volumes are the collective knowledge and expertise of spaceport operations personnel. They also are used for the evaluations of the Vision Spaceport Conceptual Analysis software toolkit.

"The VSP Strategic Planning Tool provides a standardized operability assessment of space transportation concepts using algorithms that capture the relationships between vehicle design and complexity and the corresponding requirements and costs associated with their operation at a spaceport.

- Designed to assist with design concept trade studies, subsystem trades, and operational concept trades.
- Provides an assessment of relative levels of operations cost improvements vis-à-vis current spaceport operations.
- Designed to be flexible and easily suited to upgrades, enhancements, and potential integration with other design tools."[19]

Table 7 Spaceport Module Listing

Module	Description
1	Payload/Cargo Processing Functions
2	Traffic/Flight Control Functions
3	Launch Functions
4	Landing/Recovery Functions
5	Vehicle Turnaround Functions
6	Vehicle Assembly/Integration Functions
7	Vehicle Depot Maintenance Functions
8	Spaceport Support Infrastructure Functions
9	Concept-Unique Logistics Functions
10	Transportation System Operations Planning and Management Functions
11	Expendable Element Functions
12	Community Infrastructure Functions

2.3.5.2 Aerospace Maintenance Technician Certification

There are several factors to consider when discussing the certification process and actual certification of personnel associated with launch and return space systems. The classical treatment of the topic encompasses the launch crew responsible for the safe launch of a vehicle. At the Eastern and Western Space and Missile Centers (ESMC and WSMC respectively) there exist training and certification processes associated with safety functions of specific personnel. Here certification implies a rigorous, structured process of training and testing before an individual is permitted to carry out specific responsibilities without supervision. Not all range personnel whose tasks affect safety are subject to certification. Key positions, which are certified, include the Range Safety Officer (RSO) and the Senior Range Safety Officer (SRSO). There are three stages that an RSO must go through: orientation; serving in support position; and serving as the main operator of a console.

There are three levels of certification at the ranges. The most formal is that of structured training and certification by a training officer. The second level is considered informal training and de facto certification by the supervisor. The third level is also informal and consists of on-the-job training with little or no certification. Personnel at WSMC are certified for six areas of range operations for example:

- Outside observer
- Telemetry
- Range/safety documentation
- Range/safety instrumentation
- Pre-launch/countdown
- Applying flight termination criteria

These certifications are related to safety personnel responsible for flight safety at the national ranges to include flight trajectory preparation as well as day of launch functions. These functions are performed to ensure both mission success and public safety. However, neither range has in place a certification or training program for the technicians assembling, testing, or maintaining the launch vehicles.

A certification process or program for the commercial launch arena for RLVs may have a precedence in a totally unrelated field. While the FAA has since the early days of aviation had a certification program for pilots it also adopted a certification program for aviation mechanics. Both of these certifications affect and promote public safety. The U.S. Coast Guard as well as the Nuclear Regulatory Commission also have certification programs that may act as a model for the commercial RLV industry. Each of these three certification programs have their roots in accidents. Whenever a serious accident occurs new regulations are put in place to prevent the accident from occurring again and to prevent related accidents.

The type of regulation and therefore certification requirement grows out of the type and severity of the accident. For instance the Three Mile Island accident was the forcing function for the Nuclear Regulatory Commission to reevaluate nuclear safety requirements. Changes in technology are a much slower forcing function to changes in requirements than are accidents.

As far back as 1991 the FAA Office of Associate Administrator for Commercial Space Transportation began investigating a need for and development of certification procedures and standards for launch personnel. This was published in a document titled, Draft Establishing & Maintaining a Commercial Space Launch Personnel Certification Program. Toward establishing a commercial space launch personnel certification program, they outlined three tasks that were required:

- First, determine what functions and tasks performed by commercial space launch personnel are related to safety.
- Secondly, establish a set of certification standards for the above functions and tasks.
- Thirdly, establish a certification process to evaluate candidate qualifications against the certification standards developed above.

2.3.5.2.1 Brevard Community College (BCC) Aerospace Technology Program

2.3.5.2.1.1 Aerospace Technician Program

Brevard Community College (BCC) has developed and implemented a new degree program in August 2001 called Aerospace Technician Associate of Science Degree Program. In conjunction with this also developed a skills standard development process. This was in response to the status of the aerospace industry. The aerospace industry has an aging workforce. There are twice as many in the aerospace workforce over 60 as there are under 30. Additionally, there have been industry changes due to legislation such as the Commercial Space Act and the changes in the Export Control Act. Finally, societal changes in technology and cycle times of development have changed the aerospace workforce and its focus. This has been addressed by BCC by developing aerospace technical education partnerships, a two-year college degree program, and development of National Skills Standards for competencies. Their goal was to develop and implement a program to provide employable technicians for the future aerospace industry.

An executive steering group called the Aerospace Technology Advisory Committee (ATAC) oversees the program. It is made up of industry partnerships from the government, industry, and academia, see Table 8, ATAC Partners. The Program Plan consists of a five-year implementation. In 2000 their goal was to develop the Aerospace Technician Degree and obtain aerospace industry support for a National Skills Training Program. This led to the formation of the ATAC industry working group, the development of laboratories for teaching, and opening of a spaceport center facility at KSC. The year 2001 goals included securing funding from the state of Florida, receiving an endorsement by means of a Horizon Jobs Grant, and beginning classes at the Center for Space Education at KSC. This led to the development of the curriculum using a formal process known as a Developing A Curriculum (DACUM). Additionally, laboratory equipment was acquired, on-line courses were developed, further facility development occurred and initial classes began. The 2002 phase had goals of achieving a National Science Foundation designation as a National Center of Excellence and furthering the program development. This phase includes achieving the development of the database and training programs for Aerospace Technicians, a national delivery system, and endorsements by the primary stakeholders. Follow-on activities in the 2003-2005 time call for actions to put into place the national infrastructure and begin transitioning to a fee-based self-supporting program. This will lead to a National Technicians Skills Assessment Program and tuition and fee-based programs that transition the center to self-support.

Table 8 ATAC Partners

Government		Industry		Academia	
NASA	KSC	Boeing	Wyle	Astronauts Memorial Foundation (AMF)	Brevard Community College
45th Space Wing	National Science Foundation	United Space Alliance	Pratt & Whitney	Embry Riddle Aeronautical University	Florida Institute of Technology
Brevard Workforce Development Board	Federal Aviation Administration	Florida Aviation Aerospace Alliance	Bionetics	Florida Space Research Institute	Division of Community College (DCC)
Cape Canaveral Air Force Station	Southern Economic Development Center	Dynamac	Lockheed Martin	K-12	Florida Space Institute-University of Central Florida
Technology Research and Development Authority	Florida Space Authority	Harris	Delaware North Park Services (DNPS)	Community Colleges for Innovative Technology Transfer	
Enterprise Florida, Inc. (EFI)	Education Development Center	Command Control Technologies	NIDA Corporation		
		Space Gateway Support (SGS)	Indyne		

The Aerospace Technician focus statement states: "An Aerospace Technician assembles, services, tests, operates, and repairs systems associated with both expendable and reusable launch vehicles, payloads, related laboratories, and ground support equipment."[20] The duties identified for an Aerospace Technician include assembly/disassembly, fabrication, service/de-service, testing, operations, safety, and tool control (accountability).

2.3.5.2.1.2 BCC Interview Summary

In addition to sharing the development and progress of the Aerospace Technician Program several key points were presented for which FAA-AST can affect.

- Forcing functions for the certification
    - No military training like before, i.e. fewer ICBMs and associated training
    - Older workforce is leaving a gap
    - Secondary school not graduating students at proper education level
- Industry partnerships are essential regardless of the certification issue
- Certification should come from an industry partnership with only a government endorsement
- It is understood it is too early in the process to get a government endorsement
- The desire is to get endorsement without engendering regulations for certifications
- Employ a good model for the aerospace technician certification such as the Automotive Service Excellence program

2.3.5.2.2 United Space Alliance (USA) Aerospace Maintenance Technician Certification

United Space Alliance (USA) put forth a plan for a Certification process for an Aerospace Maintenance Technician. It should be noted that USA is a partner with BCC and their effort. USA suggests that the retention of a unique and qualified workforce is an issue of safety of space flight. Experienced personnel will be required if RLVs are certified in the same way that aircraft are today. This will be unlike the Shuttle process of each flight being certified for flight.

To accomplish this they recommend a set of knowledge and skill proficiency standards similar to the BCC program. This is further outlined as follows:

- Processing Job Requirements
- Standard Job Requirements
- Unique Space Launch Job Requirements
- Hazardous Job Requirements
- Critical Mission Related Job Requirements

2.3.5.2.2.1 Operator Certification Overview

For general planning, the operator certification is defined as a "written declaration by a properly recognized certifying agency or group that an individual has adequate experience, has completed a prescribed course of study, and has demonstrated through testing and performance a specified level of proficiency in a given activity."[21] This is a proposed policy for the United Space Alliance, the company responsible for the maintenance and refurbishment of the Shuttle for each flight.

Certification would be used as a means to demonstrate levels of proficiency across a group of technicians and workers. Their recommended policy is to provide the following:

- Specific guidance for the certification requirement
- Required by all hands-on technicians and workers
- Required for all personnel who perform real-time control during flight and ground operations
- Requires industry standards for certification procedures and requirements

Their proposed certification policy requires professional and industry level certifications for:

- Technicians
- Quality Inspectors
- Quality Engineers
- System Engineers
- Safety Engineers
- Software Engineers
- Software Quality Engineers
- Safety, Quality, and Engineering Managers
- Flight Controllers
- Simulation Controllers

2.3.5.2.2.2 Certification Model

The USA certification process is essentially a four step process taking individuals from a general training environment to certification. Each certified position will have general training and experience requirements based on the position and level of certification. Next is the industry certification or equivalent degree requirement. Once this is accomplished the individual receives specialized training and experience in the specific professional or industry area. And finally the individual is certified in that area of specialization. Figure 3, Certification Model [21], highlights this process.

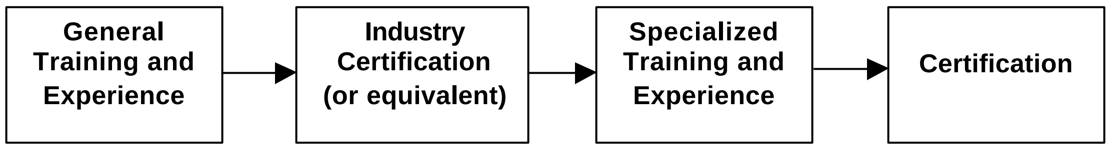

Figure 3 Certification Model [21]

Certification levels for space industry certification do not yet exist. The technician, engineer, flight controller and simulator instructor certification will be based on the FAA model. Quality certifications will use the American Society for Quality (ASQ) industry certification as its basis. Safety certifications will use the Board of Certified Safety Professionals (BCSP) as a basis. Software engineering certifications standards are to be determined, but may make use of the new

Certified Software Development Professional (CSDP) program created by the Institute of Electrical and Electronic Engineers (IEEE) as its basis. It is proposed in this policy that all certifications and re-certifications require written, oral, and practical examinations to assure knowledge and demonstration levels commensurate with the area of expertise. Figure 4, shows the Spacecraft Maintenance Technician Certification Model.

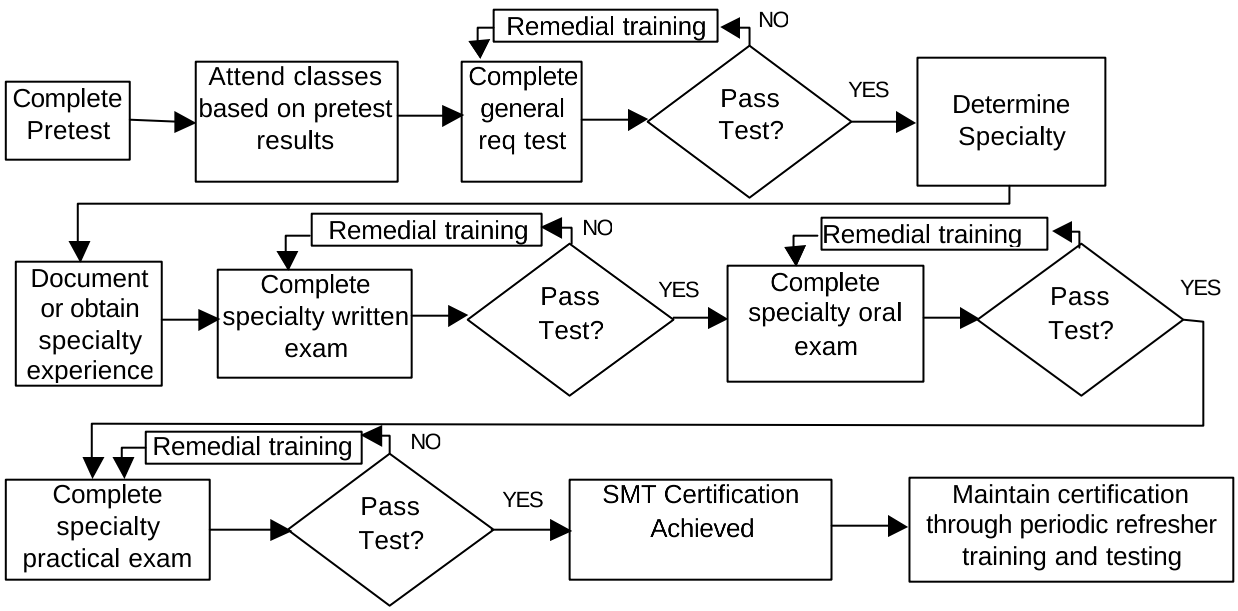

Figure 4 Spacecraft Maintenance Technician Certification Model [21]

2.3.5.2.3 Certification Criteria

The certification criteria for technician level proposed includes:

- Must be 18 years old
- High school graduate or equivalent
- Read, write, and speak English
- Pass written and practical examinations
- Have a minimum hands-on experience

Specific experience would include airframe/spaceframe repair, powerplant repair and test, hydraulic systems, exotic fuel system and handling, pneumatic system, avionics, electrical, and cryogenics, welding industrial or aerospace, refrigeration and cooling, thermal protection, ordnance pyros, spacecraft repairs and servicing.

Additionally a control board would establish policies and procedures for the certification process. This board would also establish exception rules and establish and ensure grandfather rights.

2.3.5.3 Review of Commercial RLV Inspection and Personnel Training Program Proposal

In 1996 a proposal was submitted to the FAA Office of Associate Administrator for Commercial Space Transportation for the development of an RLV inspection program and personnel training program. These programs were to develop certification criteria and operational policy, procedures, and guidelines to ensure public safety, protect the environment, and augment the regulation of the commercial RLV industry.

These programs were to be developed and implemented in seven phases: data gathering, data correlation/comparative analysis, develop RLV data set, industry/vehicle modeling, product (program) development, training program, and program implementation. The foundations of these are partially being fulfilled in this report. Under product development were 4 elements for follow-on work to this effort: develop RLV performance standards, develop RLV inspection criteria, develop/apply operations policies, and develop/apply procedure guidelines. From these the training programs for each appropriate personnel and position would be developed. These would apply to RLV manufacturers, spaceports, and RLV system operators.

Although not proposed this would lead to a certification process as mentioned above in Section 2.3.5.2.2.1.

2.3.6 Interview Summary

Several interviews were conducted with both active COMSTAC RLV developers, previous RLV development such as X-33/X-34, as well as representatives from various X-Prize contenders. Note: each of the individuals interviewed was given the opportunity to review and correct/amend the notes taken during the interview. Details of the interview are contained in Appendix E.

Please note: The following extracts are taken directly from the interviews conducted. Editing has been minimized to ensure the interviewee's original intent is maintained. Lessons learned constructed from these interviews can be found in Section 2.3.7. The interview responses reflect the perspectives of the individual or their organizations.

2.3.6.1 RLV 1 Interview: Current Developer

There are three key issues brought forward from this interview.

1. It is a necessity for the FAA to define what to design and operate to rather than how industry should get to the performance standards.
    a. This includes the FAA determining the safety factor for design, operations, and maintenance to design to.
2. An issue brought to the surface is that of the FAA 14 CFRs detailing flying qualities being reasonable.

    a. These flying qualities should be reasonable across all phases of flight, RLV has big changes in moments of acceleration – flying qualities need to be reasonable through out phases
    b. The 14 CFRs provide detailed flying qualities for aircraft, it is a consideration to have the RLV flying qualities as a subset of these.
3. It was mentioned that any vehicle design will have established criteria for success. These criteria should then use that empirically for regulation and sharing.

2.3.6.2 RLV 2 Interview: Previous Government Project

The following are key elements from the interview conducted.

1. X-34 was an operations demonstrator not only in technology but O&M as well.
    a. There were 25 flights scheduled and the goal was get turn-time down to 2 weeks or less.
    b. The goal at one time was to have only 12 people turning it around. Then it went to 10 people at the field site which included the support staff like secretaries.
2. O & M never was an underpinning of the design aspect – composite vehicle but could easily remove and replace for some turn around requirements.
3. The program was required to have the L1011/X-34 package certified.
    a. This was called certification of flights as opposed to being licensed.
    b. Very painful process and the certification of the “package” was never resolved.
4. Most of the critical remove and replace parts were made to be accessible.
    a. Toughest part was to unbolt a panel and remove it which wasn’t tough.
5. Opinion: Space industry will NEVER get to aircraft like operations
6. Military will be the driver of the technology.

2.3.6.3 RLV 3 Interview: Current Developer

The following are key elements from the interview conducted.

1. We are looking at using aircraft engines on the booster for flying it back to its launch facility.

2. The software that will control the vehicle during horizontal flight and landing will most likely use aircraft algorithms and modules.

3. Landing gear and wing designs will be patterned after aircraft designs.

4. Our launch is planned to be vertical and use rocket engines. Also the booster and orbiter are planned to return to their launch facility autonomously.

5. The vehicle health monitoring approach will rely heavily on aircraft system design for its architecture and algorithms.

6. Our operations will be drawn from ELV and Shuttle backgrounds but updated to require less hands on activity and quicker turnaround.

7. Presently the only pilots will be NASA trained and certified. The safety of the pilots and crew are the number one requirement of the human rated RLV systems.

8. Presently the only passengers will be NASA crew members. The safety of the pilots and crew are the number one requirement of the human rated RLV systems.

9. Public safety is of great importance to our RLV program and Launch vehicle autonomous flight operations in the National Airspace will need FAA approval. We need to know as soon as possible what process FAA is going to follow to license RLVs. This will allow us to design our vehicle to best protect the public.

2.3.6.4 RLV 4 Interview: DC-X

The following are key elements from the interview conducted.

1. It was unclear if a functional breakdown was done.
a. The focus from day one was if there was not a high level of reliability then the program was not doable.
2. There were too many unknowns because this stuff was not understood at the time.
3. Some operability and high-level objectives were accomplished.
4. The company tried to lay out the process: “when building commercial aircraft you know reliability of individual parts”.
a. Some work was done in standards process and some in historical process.
5. Before flying first time a database exists to give idea of what reliability will be.

2.3.6.5 RLV 5 Interview: Developer

The following are key elements from the interview conducted.

1. Our vehicle is simply an airplane with a rocket engine and capable of dealing with zero atmosphere (space).
   a. The launch occurs far enough away to keep insurance costs down.
2. Ground systems use readily available parts for pneumatics, cryogenics, electronics etc (valves, cabling, control systems, etc}.
3. "design for support" vs. "support the design" requires major flight system maturity increases.
4. Ground systems investments require higher flight rate and/or synergy (enabled) with flight system advances.
5. High -typical technician should have a few to 5 years experience before performing almost any operations alone without a more experienced lead.
6. Commercial RLVs of similar technology and reliability will likely require many of the same repair facilities and operations.

7. Only 2nd order effects may improve as one generation of technology on ground systems becomes implemented by another

2.3.6.6 RLV 6 Interview: X-33

The following are key elements from the interview conducted.

1. Since FAA doesn't regulate other government agencies' vehicles they simply were interested in traffic avoidance (for the X vehicle)
2. The purpose of the X vehicle was to prove out technology (the concept) and provide experimental verification – determination of some of the parameters and O&M
3. 3rd Major Objective was the O&M for the vehicle
    a. As part of objectives given turn around times as one of the key cost drivers was turning it around for the next mission – object was to meet turn time for normal vehicles
    b. To get turn time down – a couple things done – designed thermal protection system that was robust (unlike tiles on shuttle) so quick inspection and repair (panel off in 6 mins and another on in 6 mins) – 1200 panels on the vehicle
    c. Another thing for quicker turn was it was a single stage vehicle so didn't have to put pieces together – just checked subsystems like airplanes – you didn't have to rebuild it
4. So idea was to inspect it and have criteria for acceptability. We were intended to inspect the X vehicle manually. The RLV would have an automated inspection possibly using laser or other optical techniques.
5. To extrapolate X-33 to Venture Star did preliminary plan have O&M type actions like an MEL or min equipment list
    a. For shuttle it's 100% of everything Initially, RLVs would also require 100% (I suspect.) Eventually, as confidence was gained, some acceptable exceptions to this practice might be found.
6. The margins are not there to allow robust flexibility expected in aviation
7. Our RLV was designed to lose an engine on the pad and still fly the mission safely - may not accomplish mission but could fly to completion and land
8. It's a cultural thing that to not want a space vehicle flying over our head even if as safe as aircraft
    a. The recommendation/compromise: So do flight test over range and once proven let us fly over people – give license
    b. However, is 10 flights into flight program and safe then go inland and meet a different criteria with Ec or like criteria
9. Venture Star Operations –looked at the public safety issue – approached roughly like describing with respect to Ec
10. Going inland is a tremendous advantage – most RLVs are not going to be multistage
11. Can't get the multistage back – if they are going to be one or two stages the first stage kind of makes up for the fact at low altitude but say you are launched at some place out of Colorado or Utah – advantage is to not be at sea level

12. RLVs will never have an ability to do anything but land i.e. no avoidance maneuvers– If ATC moves everyone out of RLV's way then fine. Furthermore, RLVs are very predictable after the deorbit burn. This is the one mitigating factor for easy integration into the air traffic scenario. Furthermore, they are "quick."
    a. They won't linger in the airspace plugging up the system. The controllers like these characteristics.
13. Interviewee considers an airport SUA anyway – can't fly right through it
14. Whole industry wanted to go toward licensing realm instead of certification as it was less intrusive
15. How much technology in common with aviation maintenance. A lot, plus two additional areas: cryogenic operations and spacecraft cleanliness requirements.
    a. STS before challenger no one used tool control – tool accountability before arriving and departing tools – to prevent tool loss – aircraft (a/c) can't take off until all accounted for
    b. When went to do RLV they would incorporate all practices common in aviation, tool control, mx inspection, annuals, periodic inspections, also: high technology – IVHM. Therefore, maintenance personnel will undergo same aircraft type training requirements with the additional awareness of cryogenic ops and cleanliness practices. Attention to detail is the key!! Access to documentation for verification of questionable configuration is the key!! Lean quality control is the key!! Everyone on the maintenance/ops team is an inspector/approver and responsible for the safety of the flight!!
    c. If IVHM was advanced enough could relax maintenance activity
16. Lessons learned document on X-33 and V. Star are more technical and programmatic not O&M
    a. Never wrote down stuff he was telling us
17. The Operations and Maintenance Requirements Specifications Document (OMRSD) (provides an example of test and retest which provides opportunity to break an item that was working). AS AN EXAMPLE: sometime during the (process) flow, it takes about 73 days to process the shuttle if everything goes right, and sometime during that 73 days someone is to crawl into the cockpit and turn on the APU and go through all switches to ensure all contacts (are) being made. Then (they) have to go undo connector(s) to put test switch (unit) on it and then reassemble (the connector)
    a. So in 73 days, broke the connector, remade it, then retest(ed) it and BTW – wasn't that panel working on the last flight 40 days ago?
    b. So don't want a regulation regime that does that (to require testing and retesting to provide opportunity to break and fix an item.)

2.3.6.7 DoD 1 Interview: Air Force Space Plane

Following are key issues that came from two interviews.

1. (NAI) National Aerospace Initiative work has begun and working funding
2. NAI also includes hypersonic elements such as old NASP program –
3. USAF/AFRL GOALS are not same as NASA goals:

   a. Operability Focus
   b. Reliability Focus: Aircraft Like Operations
   c. Reduce Costs Focus
4. Military Range Commander has the call for public safety on military operations
5. Differences sited between NASA requirements and AF:

	NASA	AF
	Man Rated	Non Man Rated
Payload Needs	50-100 klbs	10-15klb
Responsive	48 Hr	12-24 Hr go to 8 Hr
Launch Rate	20-50 Missions / yr	150 Missions in 2-3 yrs
Weather	Crew safety launch on time	All Wx

6. Wants FAA to push developing and approving special flight corridors for testing RLV concepts

2.3.6.8 Insurance 1

There were a number of key issues brought forward from this interview:

1. Availability and cost of third-party liability insurance is largely dependent on demonstrated performance.
2. The starting point for determining amount of insurance that can be extended and the cost is the Maximum Probable Loss (MPL) number that must be calculated for each launch event.
3. The existence of regulations and declarations of adherence to them can sometimes hurt a client because the legal system view government regulations as only the minimum level needed to ensure safety.
4. The insurance industry is struggling with the extreme variation of risk during a particular flight. For example, once the majority of propellant is expended, the risk of a "ballistic missile" impact-like event is reduced. This is variation in risk is much more extreme than traditional aviation.
5. There is the potential for a shortage of affordable insurance if there are substantial losses in early RLV flight attempts that lead the traditional aviation community to push back on carrying the cost of such losses. [Aside: This results from space launch risk currently being distributed across the broader aviation market. The space industry is not sufficient in size to serve as it own underwriting pool.]

2.3.7 RLV Lessons Learned

There were numerous lessons learned extracted from the publications review and interview process for the RLV domain. While many of these lessons relate to business or non-safety considerations, each should be reviewed for inclusion in regulation or accompanying guidance. These are summarized and categorized below. In addition, a numbering scheme has been introduced to identify each lesson within these groups. These numbers are used in Table 15 to correlate the lessons learned with both the system functions and procedural items (discussed in more detail in Section 3.6). Additional numbers have been reserved to be used in later phases of this research effort.

2.3.7.1 Rulemaking Issues [RLV1-RLV100]

Third-party liability is not a function of operations and maintenance regulations; rather its availability and cost are almost solely determined by the MPL number required by the licensing process and demonstrated performance.[RLV1]

Regulations may actually end up being detrimental in establishing liability because the legal community almost always interprets government regulation as a minimum requirement to be met. Thus arguing that you are compliant with the rules is taken as an admission that you are doing only the minimum, and perhaps not what is standard for the industry or what is possible to protect public safety. In fact, regulations may have the adverse effect of shifting responsibility away from the RLV operator/developer.[RLV2]

The insurance market does not have a current model that fits RLV flight profiles where risk is substantially higher in the early portion of the flight, often measured in seconds of a flight that may last hours or even days.[RLV3]

RLVs should be tested and certified for high-life limits and usage, and monitored for failures. High mission reliability alone is not enough.[RLV4]

In order to extend existing aviation regulations to apply to launch vehicles, appropriate rules concerning vehicle structural integrity and damage tolerance, fire-suppression systems, passenger evacuation standards, maintenance procedures and other matters must be developed. [RLV5]

Regulatory innovation is required over a wide range of subject areas including: vehicle design approval, staff training/licensing, air traffic management, and space debris.[RLV6]

The regulatory standards called for in the Space Tourism Act are to ensure safe operation of passenger carrying launch and reentry vehicles for space tourism; and for the provision of and safe operation of habitable facilities in outer space for space tourism. Additionally, the bill calls for issuance of regulations to prevent the growth of orbital debris resulting from space tourism.[RLV7]

In developing the O&M performance criteria and standards in the next phase it is necessary to consider space tourism act and promotion of the industry.[RLV8]

A personnel certification process or program for the commercial launch arena for RLVs may have a precedence in a totally unrelated field. While the FAA has since the early days of aviation had a certification program for pilots it also adopted a certification program for aviation mechanics. Both of these certifications affect and promote public safety.[RLV9]

The forcing function for the certification of personnel working as RLV technicians and mechanics include: less personnel trained in related topics by the military, the retirement of experienced technical personnel from the space industry, and the lowering of graduation requirements / changing curriculums in the nation's secondary schools.[RLV10]

Industry partnerships are essential regardless of the certification issue.[RLV11]

Approval criteria should come from an industry partnership and the actual approvals should come from the government or designees.[RLV12]

A good model for the aerospace technician certification is the Automotive Service Excellence program.[RLV13]

It is a necessity for the FAA to define what to design and operate to rather than how industry should get to the performance standards. This includes the FAA determining the safety factor for design, operations, and maintenance to design to.[RLV14]

High -typical technician should have a few to five years experience before performing almost any operations alone without a more experienced lead.[RLV15]

[RLV16-RLV100 Reserved]

2.3.7.2 Program Processes [RLV101-RLV200]

The system operational infrastructure should be designed for "off-line" (off the launch stand/pad) vehicle system checkout to the maximum extent possible.[RLV101]

In retrospect it would have been far easier and cheaper to execute all DC-X testing (except that involving cryogenic propellant flow) within the hangar versus on the pad. In keeping with "aircraft like" operations all vehicle systems tests should have both routine preflight and post flight procedures performed.[RLV102]

An incremental test program should move from simple ground-based testing to more complex ground tests followed by flight testing designed to progressively expand the flight envelope.[RLV103]

[RLV104-RLV200 Reserved]

2.3.7.3 Safety [RLV201-RLV300]

The incorporation of an onboard automated vehicle system checkout mechanism is critical.[RLV201]

The use of an integrated ground and on-board automated systems checkout capability, initiated and controlled by the flight crew, was of profound importance in achieving rapid turnaround and minimal crew requirements. It should be the cornerstone of future system designs. It need not be overly complex, aircraft state of the art is all that's required.[RLV202]

Design should incorporate automated emergency procedures/systems.[RLV203]

Incorporate an engine out capability and an abort/emergency landing capability.[RLV204]

Independent validation and verification (IV&V) of system flight control laws and software reduces program risk.[RLV205]

It is always a good idea to have an independent "set of eyes" review detailed flight control laws and associated coding efforts. On the DC-X program this worked very well and did not affect the software introduction and testing schedule. [RLV206]

Autonomous engine shut down at landing under both normal and emergency conditions is essential.[RLV207]

The primary concern for the DC-X was the potential tipover of the vehicle under power on landing and the analysis which determined that a human could not react fast enough to compensate. Also, due to the combined damaging effects of thermal, acoustic and blast of the engine exhaust on the landing areas and systems rapid, automatic shutdown with "weight on wheels" is necessary. This is also a safety related issue for any unmanned vehicle which lands with power-on. It is of primary importance to power-on vertical landers.[RLV208]

All vertical take off RLVs should be designed for, and plan for, anomalous conditions which will result in engine out <u>and</u> flight abort capability.[RLV209]

An ancillary benefit of designing RLVs with a full flight envelope abort/ engine out capability is a significant reduction in the amount of on-board subsystem/component redundancy required to achieve a given probability of mission success.[RLV210]

In an effort to apply a previous lesson learned concerning the entrapment of explosive mixtures of hydrogen, a new and more important lesson emerges, specifically do not create traps in the name of safety. Ancillary equipment was added to avoid one problem which, in the end, led to a different and equally as lethal problem..[RLV211]

The vehicle health monitoring approach will rely heavily on aircraft system design for its architecture and algorithms.[RLV212]

[RLV213-RLV300 Reserved]

2.3.7.4 Design and Technology [RLV301-RLV400]

There exists a need for new technology development not for vehicle engineering but rather as Ground System Technology. The last development was in ‘50s with the Atlas ICBM rapid refueling requirement to fuel the ICBM as it rises out of silo. No new rapid fueling requirements have been drafted. STS uses technology developed during the Apollo era. In fact most of the ground infrastructure and methodologies are the same hold-over from that era as well. A newer approach comes from the Atlas V. It uses a new approach for fueling which drives toward safety and fewer moving parts. The Atlas V system uses pressure not pumps for fueling. While not a reusable system, the technology and methodology is applicable to RLVs. At the same time this approach reduces parts count.[RLV301]

Although transportable equipment is desirable, refrain from designing mobile buildings/hangars that must be routinely moved.[RLV302]

Moving an “aircraft” hangar over the test vehicle as was done on DC-X is not a good solution. Future systems should have the vehicle towed to and from its hangar to the launch stand or area. This is not to say the “hangar” should not be transportable, just that mobility should not be required for day to day operations.[RLV303]

The ability to do automated, rapid mission planning for reusable vehicles is essential.[RLV304]

In a truly reusable and responsive system rapid changing of mission parameters will be required to meet changing user needs. Automation will simplify accomplishment of quick reaction mission changes, and was demonstrated during the DC-X flight test program.[RLV305]

Integrated and concurrent engineering of control systems hardware and software is effective.[RLV306]

Rapid system turnaround necessary to accomplish the objectives of the DC-X test program was done through integrated and concurrent engineering and design of the control system hardware and software. [RLV307]

Thermal control for hydraulic systems, if used, must be provided and designed into the system. This was a problem on the DC-X with hydraulic lines and subsystems being located close to cryogenic temperatures. This caused a freezing or “slushing “ condition of the hydraulic fluid reducing control response times due to the slow acting fluid.[RLV308]

Designing the engine/propellant/propulsion systems should minimize the need for purging, desiccation, etc. between firings and flights. This is import for engine maintainability, supportability and inspections. Carefully implemented the vehicle turnaround time and operating costs can be dramatically reduced.[RLV309]

Reusability should be designed and built-in.[RLV310]

Ease of testing should be designed into the vehicle. Assembly of the DC-X avionics rack and its systems, and testing them with the flight operations control center (FOCC) prior to integration with the vehicle was an excellent idea paying great dividends. By proceeding in parallel with the build up of the rest of the vehicle much time was saved in the final integration.[RLV311]

A rigorous systems engineering approach drawing in all disciplines; technical and managerial should be employed. A strong lesson is the need for a real systems engineering approach. All decisions were made in support of top level functional goals established by the government versus detailed system specifications.[RLV312]

Stringent configuration control of both hardware and software changes should be adopted.[RLV313]

The program should be kept streamlined by pushing program and configuration control responsibility to the lowest reasonable level, and follow the fast track management principals defined by the DC-X government team.[RLV314]

"Design for support" vs. "support the design" requires major flight system maturity increases. [RLV315]

[RLV316-RLV400 Reserved]

2.3.7.5 Maintenance and Operations [RLV401-RLV500]

“Aircraft like” operations and support systems are compatible with rocket powered reusable launch systems. Aircraft like ground and flight operations can be accomplished.[RLV401]

“Aircraft like” does not mean the vehicle has to look like an aircraft. It means that O&S considerations must be designed in at the beginning. Design for accessibility, ease of line item removal and replacement, no special fittings, connectors, fasteners or tools to perform maintenance and following established (modified for peculiar rocket requirements) aircraft maintenance practices and tracking procedures, are but some of the “aircraft like” O & S techniques used successfully on the DC-X system. Through the use of designed in accessibility, operability and supportability in the flight vehicle.[RLV402]

Automated ground support systems reduce system processing times and size of support crew.[RLV403]

Touch labor will add time and cost. Wherever possible automation should be used to reduce the touch labor processing times and crew sizes. The DC-X used much commercially available hardware and software to automate ground processing at minimal cost.[RLV404]

Future programs should develop operations and supportability data collection systems which have direct traceability to future operational vehicle/system configurations.[RLV405]

Such systems should be based upon the aircraft model. By developing such a data collection system early in the program all O & S data can be captured, even during component and subsystem testing in the factory. With a system which maintains traceability to an operational system the eventual users of the RLV system will only have to learn one data collection method, and an extensive data base will have been built by the system's first flight <u>and</u> initial operational capability.[RLV406]

The DC-X system is in fact a complicated system which encompasses system checkout, trouble shooting, mission planning, flight simulation, loading and unloading of cryogenic propellants, pre-flight and post-flight checkout, to name but the major tasks performed. The entire DC-X system was operated by a mission management crew of three (flight manager, deputy flight manager and ground support systems manager) and a touch labor maintenance team of only seven.[RLV407]

Isolation circuits for flight critical subsystems should be designed into the vehicle.[RLV408]

A lesson which has been incorporated in the DC-X since Flight 5 is isolation of hydraulic system lines and subsystems. For any flight vehicle using hydraulic control systems, redundancy or isolation methods are needed to preclude the possibility of complete loss of hydraulics due to a single leak. Similar isolation circuits should be considered for other flight critical subsystems.[RLV409]

Propulsion system designed-in operability and supportability is just as critical as performance.[RLV410]

A propulsion system which has high performance, but does not meet operability and supportability criteria, will cost considerably more to operate and not meet the complete system requirements. We're still learning from the DC-X engines how surprisingly far you can push life and reliability, even with 30 year old technology.[RLV411]

This is a primary requirement for all subsystems of a “reusable launch vehicle”. Reusability (i.e. operability, reliability, maintainability, availability, etc.) cannot be retrofitted into a design, without excessive added cost to the program. [RLV412]

Commercial RLVs of similar technology and reliability will likely require many of the same repair facilities and operations.[RLV413]

While it may be possible to formulate a maintenance approach using tools like a minimum equipment list (as was proposed on Venture Star), it is more likely that early RLVs will require all systems be fully operational to fly. This latter approach is currently applied for the Shuttle.[RLV414]

[RLV415-RLV500 Reserved]

3.0 Data Analysis

The previous section described the data collected for the purposes of identifying those items needed for a complete, consistent, and meaningful set of O&M requirements designed to ensure public safety. This section outlines both the process and results of extracting the most relevant lessons-learned from the collected data. Whereas the previous sections were organized around the domain being surveyed, a new taxonomy is developed in this section that will allow specific O&M topics to be examined in relation to individual system functions and procedural items.

3.1 Analysis Approach and Taxonomy

In order to provide a top-down approach for the RLV O&M rulemaking effort, a way of evaluating the appropriateness and applicability of the existing 14 CFR content was needed. Such an approach allowed data collected through the various interviews and publications reviews, and current RLV practices to be combined to determine where gaps remained. The goals of this approach was to not unduly constrain design, while still taking into account the dichotomy of lessons-learned from aviation-like RLV concepts and those that are closer to a ballistic model. Given the wide range of RLV concepts currently under consideration, RTI has looked at this issue from a number of different perspectives. As noted in Section 2.1.3, the first of these related to establishing an order of priority by which to review the existing 14 CFRs predicated on the "most likely" development scenario for the RLV industry. Analysis in this section builds on this by providing specific definitions for flight phases and for both system functions and procedural areas likely to be needed for any RLV. With this set of definitions, a series of correlations were developed including reviewed 14 CFR parts to flight-phase; reviewed 14 CFR parts to functions and procedural areas; and finally, lessons-learned to both flight-phases and the system functions and procedural areas.

These correlations are the starting point for development for a functional analysis planned for in later steps of this overall effort. A model for such an approach was found in the *Status Report on Space Tour Vehicle "Kankoh-Maru"* issued by the Japanese Rocket Society in 1998, an extract from which is shown in Table 9 Example of Regulation Applicability – Japanese Space Tour Vehicle.

Table 9 Example of Regulation Applicability – Japanese Space Tour Vehicle

Airworthiness Standards			Applicability to Space Tour Vehicle	
Transport Category Airplanes - Type T			Vertical Take-off and Vertical Landing Type (VTVL)	
Items		Contents		
Chapter 1 General				
1-1	Definition	Definition of airplane type	M	Vehicle types are to be defined according to launch and landing configuration
Chapter 2 Flight				
2-1	General	Proof compliance by test or analysis	Y	
		Load distribution limit	Y	
		Max. and min. operational weight	Y	
		Allowable center of gravity travel certified by measurement	Y	
		Removable ballast	Y	
		Propeller speed and pitch angle limit	X	No propeller system

Legend: M = modified or newly defined regulations
Y = Direct applicability of existing rules
X = Does not apply at all

Table 9 highlights how, for one particular vehicle type, each regulation was reviewed and determined to either apply, apply with modification, or not apply at all. The FAA NPRM effort is complicated from the point of view that any resulting rules must work for a broad range of vehicle concepts and flight profiles. It is conceivable that someone may propose an RLV that integrates propellers or rotors into their design (consider the proposed ,but now defunct, Roton design).

3.2 RLV Operations and Maintenance Phasing with the NAS

The RTI team applied a phased approach for 14 CFR applicability and gap identification. It is envisioned that the “generations” of RLV development will follow a path that may initially be lead by a small craft leading up to a larger transport type craft.

It is likely that the RLV community will initially use the airspace in the same manner that current launch systems use the National Air Space (NAS) today. This is accomplished through the declaration of Special Use Airspace (SUA). Notices to Airmen (NOTAMs) are currently used to inform the broader aviation community of launch activity, and a similar system is used to warn mariners. SUAs and the NOTAM system are expected to be retained for some time to come. This period is referred to as Set 1. Airspace utilization will develop in parallel with the development of RLV design technologies. Several Concepts of Operations (CONOPS) were reviewed regarding the integration of RLV craft into the NAS. There is likely to be a transitional period that will be a semi-integrated use of the airspace. While some RLV concepts may use SUAs and land at a pre-designated recovery site, others will begin to use airstrips for take-off and/or landing. This transitional time period is considered Set 2. When RLV technology and operations mature to a point where they can "fly" with conventional aircraft the NAS will be fully integrated. This time period is referred to as Set 3. The idea of a staged integration of RLVs with the NAS provides a framework for bridging the existing models for O&M employed today and those that will need to be developed for RLVs.

3.3 14 CFR Breakout by Flight Phase

In conducting the various publications reviews, it was noted that there is a large amount of variation in how flight-phases are defined. RTI has attempted to use the most common definitions, in some cases pulling elements from multiple sources to provide an aggregate definition that makes sense for this effort. There are five major phases of flight for an RLV considered in this effort. They are Pre-launch, Launch, Orbit/Sub-Orbit, Land/Recovery, and Maintenance. It should be noted that these phases of flight in this report represent the same phases of flight outlined in Advisory Circular (AC) 431.35-2. One distinction is that AC 431.35-2 further breaks down the Land/Recovery phase into 3 sub-phases. Table 10, provides a correlation between the aviation and RLV phases of flight, as well as the 14 CFR parts reviewed in this initial effort. This was a necessary stepping-stone to the ultimate goal of correlating a set of functions, the phases of flight, and the applicable 14 CFR parts. This can be thought of as a way of marrying the top-down approach contained in this effort with a bottom-up examination of the existing 14 CFRs, currently being accomplished within the FAA.

Table 10 SET 1 (SUA) RLV Flight Phases 14 CFR Correlation

<table>
<tr><td>Aviation →</td><td>Pre-Flight</td><td>Taxi & Take-off</td><td>Climb</td><td>Cruise</td><td>Descent</td><td>Landing</td><td>Maintenance</td></tr>
<tr><td>RLV →</td><td>Pre-Launch</td><td colspan="2">Launch</td><td>Sub-orbit/Orbit</td><td colspan="2">Land/Recovery</td><td>Maintenance</td></tr>
<tr><td>14 CFRs</td><td>11, 13, 21, 33, 34, 91, 135, 139, 381, 400, 401, 404, 405, 406, 413, 415, 420, 431, 440</td><td colspan="2">11, 13, 21, 23, 33, 34, 91, 135, 139, 400, 401, 404, 405, 406, 413, 415, 420, 431, 440</td><td>11, 13, 21, 23, 33, 34, 91, 135, 400, 401, 450</td><td colspan="2">11, 13, 21, 23, 33, 34, 91, 135, 139, 400, 401, 404, 405, 406, 413, 431, 433, 450</td><td>11, 13, 21, 33, 34, 39, 43, 65, 145, 400, 401</td></tr>
</table>

3.3.1 Flight Phase Definitions – RLV and Space Operations

The following sections provide brief definitions for each of the considered flight phases for orbital and suborbital reusable vehicles.

3.3.1.1 Pre-Launch

The phase, which can occur over many months or just weeks prior to launch, includes mission planning, trajectory analysis, all scheduling activities, and fueling the vehicle. This phase includes all activities which occur up to launch commit.

3.3.1.2 Launch

This phase includes launch commit, count-down, and flight of the vehicle to the height of its suborbital trajectory or to orbit insertion. This phase of flight may extend due to RLV stage drops and the associated airspace allocations necessary for public safety.

3.3.1.3 Orbit/Sub-Orbit

The orbit or sub-orbit phase commences upon orbit insertion at the end of the launch phase. Orbit phase includes all operations in space while on orbit including the necessary preparation for de-orbit and final de-orbit manuevers. Sub-orbit phase commences at the end of the launch phase sub-orbit injection. This may include a ballistic lofting manuever and includes the coasting phase of the flight.

3.3.1.4 Land/Recovery

The final phase of the RLV flight includes the landing commit decision, de-orbit preparations, de-orbit maneuver (or burn), re-entry, landing, and recovery. Recovery may be taxing to a hanger, towing, or recovery from a water landing.

3.3.1.5 Maintenance

While not a true phase of flight, a Maintenance phase was added to address all of the nominal maintenance, depot maintenance, and any repair work necessary to bring the RLV into flightworthiness status.

3.3.2 Flight Phase Definitions – Traditional Aviation

The following sections provide brief definitions for each of the considered flight-phases for traditional fixed-wing aircraft. Rotorcraft flight phases are similar but omit the need for a takeoff and landing roll.

3.3.2.1 Pre-Flight

Preflight is the phase of flight where the pilots check the aircraft before taxi and takeoff. This is the phase when walking around the aircraft and pilot checklists are used. Weather briefings and other information sessions from operations centers also help the pilots prepare for the flight.

3.3.2.2 Taxi and Takeoff

Taxi and takeoff, the second phase of flight, includes the surface movement of the aircraft from a gate, hangar, or other “parking” location to the end of an active runway, coordination with air traffic control on specific clearance to takeoff, the takeoff acceleration roll, and rotation of the aircraft followed by attainment of flight. The terminal area controller controls the airplane during taxi and take-off;

then the departure controller controls the flight. The phase ends with a handoff to the en-route controller.

3.3.2.3 Climb

Climb includes ascent of the aircraft out of ground-effect and generally out of a terminal airspace to a defined or clearing cruising altitude.

3.3.2.4 Cruise

Cruise typically represents the longest portion of a flight; is often largely accomplished though use of a flight management system coupled with an autopilot; and represents the transit from the end of climb from the departure airport to a point where descent to a destination airport begins.

3.3.2.5 Descent

Descent typically involves a sequence of stepped altitudes defined by an approach or by ATC that lines up an aircraft with a runway at the destination airport and at a proper altitude to land and stop without overshooting the end of the runway.

3.3.2.6 Landing

Landing consists of receipt of a clearance to land, usually sequenced by ATC with other arriving and departing aircraft; the final descent and flare of the aircraft to allow landing gear to contact the ground in the proper sequence; and then slowing the aircraft to an appropriate taxi speed. The aircraft is then taxied to a gate or other parking area.

3.3.2.7 Maintenance

Maintenance consists of both preventative and non-routine aspects and may include repair, overhaul, and in some cases, alteration of the aircraft in keeping with its approved design.

3.4 Function List

To allow development of more focused O&M regulations and guidelines, it was necessary to identify a common set of functions that would be expected to be found in RLV designs. Drawing from similar function lists that are used in traditional aviation and the Shuttle, an aggregate list was prepared for use in this effort going forward. In addition, a set of “procedural” areas was also developed to capture issues that will need to be addressed as part of the RLV O&M NPRM. Each of these lists is shown in Table 11.

Table 11 System and Procedural Functions

Note: Items with an asterisk in this table refer to License requirements currently being required.

Systems Functions	Procedural Items
1. Propulsion	1. Administration*
2. Communication	2. Design Approval
3. Navigation	3. Production Approval
4. Flight Controls	4. Operations Approval - Ground Operations*
5. Electrical/Wiring	5. Operations Approval – Flight Operations*
6. Thermal Protection	6. Licensing*
7. Environmental Systems	7. Launch Approval*
8. Surveillance	8. Continued Flightworthiness
9. Software	9. Problem Reporting & Tracking*
10. Propellant Management	10. Risk Assessment & Management*
11. Flight Safety System	11. Safety Assurance*
12. Ground Support Equipment	12. Mission Assurance
13. Payload/Cargo	13. Training*
14. Structures	14. Inter- & Intra-Agency Coordination*
15. Avionics	
16. Hydraulics	
17. Pneumatics	
18. Landing / Recovery Systems	
19. Health Monitors & Data Records	
20. Crew Systems	
21. Facilities	

3.4.1 Systems Functions Definitions

The following sections provide a definition a top-level discussion of the various systems functions. Detailed guidance for each of these areas will need to be developed in future phases of this effort.

3.4.1.1 Propulsion

RLVs require two areas of significant technology development that are "space" specific. The first is materials (e.g. thermal protection – see below) and the second is propulsion. Whereas conventional aircraft are typically limited to either reciprocating engines or turbojet designs, RLV developers must incorporate some form of rocket propulsion in their designs. The energy required to achieve orbit or sub-orbit is unparalleled in aviation. In addition to the high thrust, these engines may require propellants that present operational and maintenance challenges. Carriage of rocket fuels also may present unique hazards for which guidelines and rules will need to be derived from the space industry. Specific attention must be paid to the phase of flight where propulsion is transitioned from air-breathing equipment, if used, to all rocket. RLV propulsion technologies may include ramjet or scramjets.

3.4.1.2 Communication

Communication for RLVs must be viewed from several perspectives. Since many forms of terrestrial communications may have insufficient range to support operations in the upper atmosphere and in space, new forms of communication may need to be developed for interaction with the existing ATC infrastructure. The specific types of communications equipment along with the need for backup communications need to be considered. Note that there is also a need for a new terrestrial communications link between ATC and any required mission control. The introduction of RLV-related communications will likely take place coincident with traditional aviation's move to data link for most routine communications.

3.4.1.3 Navigation

Historically, navigation for spacecraft has been performed from the ground as computation capability onboard was limited to complete the demands of space navigation. However, many Expendable Launch Vehicles now use an inertial guidance system that provides the vehicle's position. It is only considered "pilot in the loop" navigation during docking and some rendezvous missions. This has begun to change as evidenced by the onboard navigational capability of the Shuttle. Conventional ground-based aviation navigational aids may not have sufficient range or appropriate reference systems to be of use in the upper atmosphere or in orbital trajectories. Further evaluation and study is required to determine the extent to which GPS can be relied upon for the majority of planned RLV operations.

3.4.1.4 Flight Controls

For the purposes of this document, flight controls include all aerodynamic and reactive control mechanisms for producing pitch, roll, or yawing motion in the RLV. Particular attention needs to be paid at the point when aerodynamic control surfaces no longer function due to insufficient dynamic pressure. Winged RLVs will utilize control surfaces similar to what aircraft use as well as reaction control rockets that conventional spacecraft use. Concepts will vary on the implementation of these controls and the associated transition between these two methods. Many of the current RLV concepts use suborbital trajectories targeted at obtaining altitudes where transitional flight control is likely to be of concern.

3.4.1.5 Electrical/Wiring

For the purposes of this document, the electrical and wiring functions include all onboard generation of electrical power, power distribution, and emergency power provision. Significant lessons-learned from both the aging aircraft programs of the FAA and the experiences in decades of space programs exist to help in this area. This information needs to be analyzed to identify the key items requiring regulatory guidance. Emergency power provision includes the use of onboard Auxiliary Power Units (APUs). One item of particular interest in this area is the use of sneak circuit analysis, the design verification technique that originated at Boeing as a means of evaluation and isolating the source of the Apollo 1 fire, and which was subsequently required for all follow-on NASA programs. Sneak circuits are usually the result of a design decision and do not require a component to fail to manifest themselves as an unintended function of the system. The FAA will need to make a determination of whether specific types of verification such as this should be a part of the licensing effort.

3.4.1.6 Thermal Protection

Thermal Protection is the other area that is unique to space flight and is directly related to materials. This area does not have a clear corollary in traditional aviation and is a place where significant research is underway. It is a common issue across all RLV concepts and will probably require an evolving regulatory position as more is learned about how to address this issue. Ablative shielding or active cooling (such as that on the SR-71) represent options that the FAA will need to determine whether specific guidance is needed.

3.4.1.7 Environmental Systems

For the purposes of this document, environmental systems are constrained to those systems used to provide the necessary life support to sustain living occupants onboard an RLV throughout its entire flight regime. These systems may include atmospheric control [temperature, pressure and composition (e.g., O_2 and CO_2 levels)] and supply, water treatment, and waste management.

3.4.1.8 Surveillance

Surveillance is defined as the detection, tracking, characterization, and observation of aircraft, other vehicles, and weather phenomena for the purpose of conducting flight operations in a safe and efficient manner.[iii] It is envisioned that the initial round of RLVs will continue to use Special Use Airspace and grow into integration into the ATC. Using SUA still requires surveillance of the RLV. The surveillance will be managed by either government facilities or new commercial facilities requiring guidance as well. As this develops more robust and longer range surveillance equipment will be required for tracking RLVs on approach.

3.4.1.9 Software

For the purposes of this document, software refers to any coded computer language used to control or interface with onboard systems. In the past, latent software errors have been the source of catastrophic mission failures in the space domain, and have been similarly indicted in a number of aviation mishaps. For traditional aviation, the FAA requires specific design assurance be applied to

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[iii] RTCA *Government/Industry Operational Concept for the Evolution of Free Flight, Edition 2*, August 16, 2000; RTCA Free Flight Steering Committee; Washington D.C.

all safety-related software onboard aircraft.[iv] Space launch systems including Launch Control Software, Telemetry, Tracking and Control Software, and Vehicle Health and Management Software, may require such design assurance to ensure system stability, reliability, integrity, and availability. Software used in simulations and models that may affect a mission's safety should also be assured in a similar fashion.

3.4.1.10 Propellant Management

For the purposes of this document, propellant management includes all elements of propellant feed, pressurization, and control throughout the RLV's flight regime. Considerable effort has been put into developing techniques, tools, and strategies for identifying leaks in propellant feed systems, although in many cases the techniques in current use date back to the early days of space exploration. At least one RLV concept currently being pursued in the commercial market involves cryogenic propellant loading in flight.

3.4.1.11 Flight Safety System

The primary purpose of a flight safety system is to monitor a launch vehicle's flight status and provide the positive control needed to prevent the launch vehicle from impacting populated or other protected areas in the event of a vehicle failure. The requirements for properly qualifying the proposed flight safety system and validating its performance are critical. Comprehensive flight safety system requirements must be provided that are designed to ensure that a launch operator implements a highly reliable, acceptable system.[v] Note the FSS includes the more traditional Flight Termination System (FTS) often used for unmanned rockets. Questions that will need to be answered for these systems include: the level of required automation, the possibility for off-board or hybrid safety systems, the interaction of the crew with such systems including their ability to override, and whether certain vehicles could be allowed to fly without such a safety system.

3.4.1.12 Ground Support Equipment

For the purposes of this study, Ground Support Equipment (GSE) is defined as the collection of tools, systems, and infrastructure needed to prepare an RLV for launch, service the RLV on the ground, and recover the RLV following a flight. Typical GSE will include towing apparatus, fueling stands and trucks, and on-ground off-board power provision. Some point-to-point RLV concepts may also include baggage-handling systems.

3.4.1.13 Payload/Cargo

For the purposes of this document, payload/cargo is defined as any item to be carried onboard an RLV, whether it is intended for release during the flight or return with the vehicle. Neither the term payload nor cargo is intended to include human passengers. In general, payload and cargo definitions are outside of the

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[iv] Accomplished through the application of DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*.

[v] 14 CFR Parts 413, 415, and 417 Licensing and Safety Requirements for Launch; Notice of Proposed Rulemaking; Proposed Rule

O&M considerations presented herein. However, as in the case of aviation, the FAA may find it necessary to place limits on the carriage of certain payloads or cargo due to the risk posed to the safety of the onboard occupants (e.g. oxygen-generating canisters).

3.4.1.14 Structures

Structures include both primary and secondary components that provide the physical definition and strength to maintain the spacecraft's integrity. Horizontal Takeoff/Horizontal Landing (HTHL) RLV's will likely possess similar structural components to traditional aircraft including wings, fuselage, and empennage. Vertical Takeoff/Vertical Landing (VTVL) RLV's structure will likely reflect traditional fuselage and capsule designs similar to those used in space travel previously.

3.4.1.15 Avionics

For the purposes of this document, avionics is broadly defined to include all onboard systems that are dependent on electronics for their operation. This includes the control computers that are interfaced to the physical flight controls. Significant requirements and design guidance exist for traditional aircraft avionics' suites, many of which have been adapted for use in the Space Shuttle. O&M concerns for RLV avionics will need to draw from extensive experience from both the aviation and space domains.

3.4.1.16 Hydraulics

For the purposes of this document, hydraulics includes all system components designed to create, transmit, and consume hydraulic power onboard the vehicle. Hydraulic systems typically consist of low and high-pressure components including lines, pumps, actuators, reservoirs, power transfer units, accumulators, and a power conducting medium, e.g. hydraulic fluid. Hydraulics have been a source of considerable maintenance problems on the Space Shuttle.

3.4.1.17 Pneumatics

Pneumatics are similar to hydraulics except the conducting medium is a gas. Typical aviation pneumatic systems consist of bleed air systems used for deicing, cabin heating, and engine start. For RLVs pneumatics use may also include pressurization of propellant tanks and operation of valves.

3.4.1.18 Landing/Recovery Systems

For the purposes of this document, landing and recovery systems include all forms of spacecraft systems involved to bring the craft and its occupants safely back to Earth. This may involve traditional undercarriage design typical of modern aircraft (e.g., landing gear, skis, pontoons), parachute systems, and balloon-like cushions.

3.4.1.19 Health Monitors & Data Recorders

Integrated Vehicle Health Monitors (IVHM), or Vehicle Health Monitoring Systems (VHMS) as they are sometimes known, are an integral part of many modern aircraft, as well as the Space Shuttle. A uniform system of cautions, warnings, and alerts are used in the aviation domain to inform the flight crew of system changes or failures that may require attention. For the purposes of this effort, health monitors are broadly defined to include all such monitoring and alerting systems. This includes integral central maintenance correlation and consolidation mechanisms.

For the purposes of this report, data recording devices include equipment for capturing onboard operating characteristics and configuration data to facilitate maintenance activities, accident investigation, procedural optimization, and training. These recording devices may include visual, audio or data capture only, as well as real time downlink of on board information. To further distinguish the data recording function from other functions listed here, it is assumed that flight crews would not interact with the data recording system.

3.4.1.20 Crew Systems

For the purposes of this document, crew systems has been broadly defined to include all onboard systems and system design elements that provide the Human-Machine Interface (HMI) and provide life support to the flight crew. Note that this section is related to environmental systems (discussed above). Common systems may be used to support both the crew and any passengers.

3.4.1.21 Facilities

O&M activities for RLVs are expected to require some amount of dedicated facilities. These are likely to involve the handling of hazardous materials, unique ingress/egress systems, and mission control. The FAA may need to consider O&M-related regulations and guidelines for these ground-based facilities if there is a potential impact on the safety of the RLV or a safety threat posed to the public. Note: Facilities are fixed assets and are not intended to be moved from one location to another between or during missions. This is the distinguishing characteristic between facilities and ground support equipment.

3.4.2 Detailed Treatment of Procedural Items

3.4.2.1 Administration

Administration is a broad term used to describe the activities associated with coordination and administering the regulations and associated guidance for the licensing process. Coordination involves both inter-agency and intra-agency activities (see Sections 3.7.5.1and 3.7.5.2). Administrative infrastructure associated with O&M will likely include new activities for aviation inspectors; the possible assignment of Principle Maintenance Inspectors (PMI) to specific RLV operators; the evaluation of credentials and granting of operator and maintained licenses; the registering of RLV vehicles; and the associated tracking of licenses granted for RLV operations.

3.4.2.2 Design Approval

Design approval is the determination that a particular design of a system complies with all necessary regulations governing that device. For traditional aviation, the processes for this approval are contained in 14 CFR 21. Design approval is currently outside the scope of AST's licensing regime.

3.4.2.3 Production Approval

Within the aviation domain, design and production approvals are accomplished separately. The current licensing approach does not directly allow for manufacturing approval. It will need to be determined to what extent in-service O&M activities rely on production activities.

3.4.2.4 Operations Approval - Ground Operations

Operational approval is currently subordinate to the licensing approval provided by AST. For the purposes of this report, specific items relating to RLV O&M that provide the FAA with a measure of an operator's readiness to conduct operations have been highlighted from the 14 CFRs reviewed. Two distinct categories of operations are captured in the aviation FARs and are similarly discussed in the various NASA documents reviewed. These are ground operations and flight operations.

3.4.2.4.1 Ground Operations

Ground operations include all vehicle preparation and movement prior to liftoff or launch and all post-flight activity following touch-down. This may include training of involved personnel; equipment certifications associated with GSE or facilities; and interactions with controllers. Ground operations would also need to include the determination it is safe to launch, i.e., evaluation of launch-commit criteria.

3.4.2.5 Operations Approval – Flight Operations

Operational approval is currently subordinate to the licensing approval provided by AST. For the purposes of this report, specific items relating to RLV O&M that provide the FAA with a measure of an operator's readiness to conduct operations have been highlighted from the 14 CFRs reviewed. Two distinct categories of operations are captured in the aviation FARs and are similarly discussed in the various NASA documents reviewed. These are ground operations and flight operations.

3.4.2.5.1 Flight Operations

Flight operations include all vehicle movements following liftoff/launch through touchdown. This may include training of flight crews; any required training for passengers; execution of normal and emergency checklists associated with vehicle operation; performance of in-flight maintenance actions for extended flights or off-nominal maintenance required in an emergency; and commanded vehicle movements per controller instructions. This category would include adherence to both rules of conduct and rules of flight by the flight crew. Flight operations would also need to include the determination that it is safe to launch, i.e., evaluation of landing-commit criteria.

3.4.2.6 Licensing

Licensing is the primary approval mechanism formalized in the CFR for commercial space operations. Licenses are granted for each launch and are primarily focused on public safety considerations. The Procedural Items that are currently required during Licensing include: Administration tasks; Operations

Approval-Ground Operations; Operations Approval-Flight Operations; Launch Approval; Problem Reporting and Tracking; Risk Assessment and Management; Safety Assurance; Training; and Inter-&Intra-Agency Coordination. The licensing process includes assessment of risk of vehicle failure on public safety, launch and recovery site approval, and operational approval including coordination with appropriate air and mission controllers. The current licensing approach does not include manufacturing approval.

3.4.2.7 Launch Approval

Launch approval is an integral part of the current licensing regime. It is the process by which FAA/AST grants formal approval to perform a commercial launch.

3.4.2.8 Continued Flightworthiness

Continued flightworthiness is defined as the actions taken to ensure a craft continues to be operated and maintained in compliance with its original type design. This frequently requires specific maintenance actions to combat the effects of corrosion, fatigue, and general wear resulting from aircraft operations.

For traditional aviation, original equipment manufacturers have been responsible for producing Instructions for Continued Airworthiness (ICA) as part of the certification process. The current licensing approach (i.e., 14 CFR 431) does not require ICAs and does not take into consideration repeated license applications for the same craft. It is likely that the O&M regulations and guidelines will need to address this. There are numerous lessons-learned from the aviation community that can be drawn on in this area.

3.4.2.9 Problem Report & Tracking

As noted earlier, 14 CFR 21 requires the notification of the FAA if a potential safety-related problem that could be systemic is found either during operations or in the process of accomplishing maintenance. Similar RLV O&M requirements will need to be established along with basic problem reporting system requirements for the RLV operators and maintainers themselves.

3.4.2.10 Risk Assessment & Management

The current E_c approach is directed at assessing risk to populations on the ground. Since O&M activities relate to the state of the RLV, a means of tying the risk assessment/management approach together with safety assurance (see below) will need to be developed. It should be noted that there is no direct parallel to this activity for traditional aviation. This distinction has the potential to be a limiting factor in the evolution of the RLV industry.

3.4.2.11 Safety Assurance

Safety assurance in the traditional aviation domain is accomplished by application of a rigorous System Safety Assessment (SSA) process. This process, outlined in Aerospace Recommended Practice (ARP) 4754, *Certification Considerations for Highly Integrated or Complex Aircraft Systems*, calls for an initial functional hazard assessment (FHA) that is then used to assign criticalities to aircraft systems. Assumptions used in these assignments coupled with design assurance and fault tolerant system architectures are used to arrive at a required integrity and availability for each system.

In absence of an initial design approval, the FAA will need to obtain confidence that sufficient safety assurance for RLV systems and equipment is maintained during and following O&M activities.

3.4.2.12 Mission Assurance

Mission assurance is a term used in the space domain to ensure adequate protections are in place to allow the mission to complete successfully. This is generally not a focus of the FAA in the aviation domain. Rather mission (flight) completion is a business issue. In other words, the safest place for an airplane is parked at the gate. Aviation FARs are constructed in such a way that you either do not fly or you land at the earliest opportunity if continued safe flight and landing is in any way jeopardized. Given the economic damage of mission failure to the RLV and space industry as a whole, the FAA may need to consider a different paradigm for the space-related O&M requirements. Given the focus of this report on public safety, mission assurance is excluded.

3.4.2.13 Training

RLVs are specialized vehicles with many specialized aspects requiring training. A few of the examples are pilots, mechanics, repairmen, and traffic controller. Schools that provide the training as well as tools such as flight simulators used for the training are regulated in the aviation domain. Also, curricula in these schools are updated to keep up with the changing technology. Instructors have specific requirements.

3.4.2.14 Inter- & Intra-Agency Coordination

There are many agencies in the government who have the responsibility for certain aspects affected by the RLVs such as environmental safety, accident investigation, promotion of commerce, use of frequency etc. Such issues have to be resolved, just as in the aviation domain, by establishing rules that are consistent between the agencies. Also needed are clear boundaries of responsibilities and authority in these areas of overlap. Such issues must be negotiated and resolved possibly through memoranda of understanding.

3.5 Breakout of Subparts of the 14 CFRs by Function

Using the System Functions defined above allows a top-down look at the current 14 CFRs and their correlation to these functions, lessons-learned, and equally important, gaps. Table 12, Set 1 (SUA) Super Function RLV Flight Phases O&M Correlation, correlates the Functions against the Phase of Flight referencing whether there are (M)aintenance regulatory concerns, (O)perations regulatory concerns, or (-) no regulatory concern.

Table 12 SET 1 Super Function RLV Flight Phases O&M Correlation

Functions (Aviation / RLV)	Pre-Flight Pre-Launch	Taxi & Take-off, Climb Launch	Cruise Sub-orbit/Orbit	Descent, Landing Land/ Recovery	Maintenance Maintenance
Systems Functions					
Propulsion	M	O	O	O	M
Communication	M, O	O	O	O	M
Navigation	M	O	O	O	M
Flight Controls	M	O	O	O	M
Electrical / Wiring	M	O	O	O	M
Thermal Protection	M	-	-	O	M
Environmental Systems	M, O	O	O	O	M
Surveillance	M, O	O	O	O	M
Software	M, O	O	O	O	M, O
Propellant Management	M, O	O	O	O	M
Flight Safety System	M	O	-	O	M
Ground Support Equipment	M	O	-	O	M
Payload / Cargo	M, O	O	O	O	M
Structures	M	-	-	-	M
Avionics	M	O	O	O	M
Hydraulics	M	O	O	O	M
Pneumatics	M	O	O	O	M
Landing / Recovery Systems	M, O	-	-	O	M
Health Monitors & Data Recorders	M, O	O	O	O	M, O
Crew Systems	M, O	O	O	O	M, O
Facilities	M, O	M, O	O	M, O	M, O
Procedural Items					
Administration	-	-	-	-	-
Design Approval	-	-	-	-	-
Production Approval	-	-	-	-	-
Operational Approval Ground Operations	M, O	O	-	O	M, O
Operational Approval Flight Operations	M, O	O	O	O	M, O
Licensing	O	O	O	O	O
Launch Approval	O				
Continued Flightworthiness	M	-	-	-	M
Problem Reporting & Tracking	M, O	M, O	M, O	M, O	M, O
Risk Assessment & Management	O	O	O	O	-
Safety & Mission Assurance	M, O	O	O	O	M, O
Training	M, O	M, O	M, O	M, O	M, O
Inter- & Intra-Agency Coordination	M, O	M, O	M, O	M, O	M, O

The 14 CFR subparts, which appear in **bold,** in Table 13 and Table 14, are subparts, which have questions or comments concerning them that came to light during the review process. These comments and questions are found in detail in Appendix D and are summarized in the next section. In order to extract the pertinent lessons-learned and gaps these bolded subpart issues were examined for each function.

Table 13 SET 1 System Function RLV Flight Phases 14 CFR Correlation

Aviation	Pre-Flight	Taxi & Take-off / Climb	Cruise	Descent / Landing	Maintenance
Functions / RLV	**Pre-Launch**	**Launch**	**Sub-orbit / Orbit**	**Land/ Recovery**	**Maintenance**
Systems Functions					
Propulsion	135.169, 135 App A	91.126,135.169, 135 App A	135.169, 135 App A	91.126, 135.169, 135 App A	34.62**, 66.73**, **66.91**,91.126,135.169,135.443, 145.37, 135 App A, 21.128, 21.129, 23.1303, 23.1305, 23.1309, 23.1311, 23.1321, 23.1322, 23.1377, 23.1331, 33 (all), 145 (all)
Communication	**91.126, 91.127, 91.129, 91.130, 91.131 91.135,** 91.183, 91.185, 91.905, 135.67	**91.126, 91.129, 91.130, 91.131, 91.135,** 91.183, 91.185, 135.67	**91.129, 91.130, 91.131, 91.135,** 91.183, 91.185, 91.511, 135.67	**91.126, 91.129, 91.130, 91.131, 91.135,** 91.183, 91.185, 135.67	**91.129, 91.130, 91.131, 91.135,** 91.511, 91.905, **135.161, 135.163, 135.165,** 23.1303, 23.1309, 23.1311, 23.1321, 23.1322, 23.1331, 145 (all)
Navigation	**65.37, 91.13,** 91.905, 135.67, **135.161**	**65.37, 91.705,** 135.67, **135.161**	**65.37, 91.703, 91.705, 91 Appendix C,** 135.67, **135.161**	**65.37, 91.705,** 135.67, **135.161**	**135.161, 135.163, 135.165, 21.197,** 23.1303, 23.1309, 23.1311, 23.1321, 23.1322, 23.1331, Part 91 Appendix G, 145 (all)
Flight Controls	135.147,	135.147,	135.147,	135.147,	23.1303, 23.1309, 23.1322, 23.1331, 145 (all), 23.865
Electrical / Wiring					23.867, 23.1331, 23.1351-1367, 33.28, 33.37, 145 (all)
Thermal Protection					145 (all)
Environmental Systems	**135.170**, 431.91-93, 433.7-9,				**135.170**, 145 (all)
Surveillance	135.173, 135.175,	135.173, 135.175,		135.173, 135.175,	135.173, 135.175, 145 (all), 43 Appendix F
Software					
Propellant Management	34 (all)	34 (all)	34 (all)	34 (all)	34 (all), 145 (all)
Flight Safety System		**135.19**,	**135.19**,	**135.19**,	145 (all)
Ground Support Equipment					
Payload / Cargo					
Structures					145 (all)
Avionics	135.144, **135.153**, **135.154**, **135.159**, 135.163, 135.165,	135.144, **135.153**, **135.154**, **135.159**, 135.163, 135.165,	135.144, **135.153**, **135.154**, **135.159**, 135.163, 135.165,	135.144, **135.153**, **135.154**, **135.159**, 135.163, 135.165,	145 (all)
Hydraulics					23.1435, 145 (all)
Pneumatics					145 (all)
Landing / Recovery Systems					145 (all)
Health Monitors & Data Recorders	**91.205-211,91.215-91.223,135.151**, **135.152**, 135.**App B**-F,	**91.205-211, 91.215-91.223,135.151**, **135.152**, 135.**App B**-F,	**91.205-211, 91.215-91.223,135.151**, **135.152**, 135.**App B**-F,	**91.205-211, 91.215-91.223,135.151**, **135.152**, 135.**App B**-F,	135.**App B**-F, 91 Appendix E, 145 (all)
Crew Systems	91.517, 91.521-525,91.535,91.607-609,91.613,**135.12**, 135.115, 135.155, 135.156, **135.167**, **135.177**, **135.178**,	**91.307,** 91.509,91.517, 91.521-525, 91.535, 91.607-609,91.613,**135.12**, 135.115, 135.155, 135.156, **135.167**, **135.177**, **135.178**,	**91.307,** 91.509,91.517, 91.521-525, 91.535, 91.607-609,91.613,**135.12**, 135.115, 135.155, 135.156, **135.167**, **135.177**, **135.178**,	**91.307,** 91.509,91.517, 91.521-525, 91.535, 91.607-609,91.613,**135.12**, 135.115, 135.155, 135.156, **135.167**, **135.177**, **135.178**,	**91.307,**91.517,**135.177**, **135.178**, 145 (all)
Facilities	135.125, 420.19-21, 420.63-71, 420.App A-E, 433.5,	420.63-71		**139.315-319**, 420.63-71	135.125, **139.307-343**, 420.63-71, 145.35, 145.37

Table 14 SET 1 Procedural Items RLV Flight Phases 14 CFR Correlation

Functions / Aviation / RLV	Pre-Flight	Taxi & Take-off	Climb	Cruise	Descent	Landing	Maintenance
	Pre-Launch	**Launch**		**Sub-orbit / Orbit**	**Land/ Recovery**		**Maintenance**
Procedural Items							
Administration	11 (all), 13 (all), 135.1, 135.2, 135.3, 135.7, 135.21, **135.23**, 135.41, 135.63, **135.64**, 135.77, 135.81, 381.7-13, **383.1-2**, 431.21-25,	11 (all), 13 (all),**440.1-19**, **440.App A-B**,		11 (all), 13 (all),	11 (all), 13 (all),450.1-19, 450.App A-B,		11 (all), 13 (all), 145 (all), 183 (all), 381 (all), 383 (all)
Design Approval	21 (all), 33 (all)	21 (all), 33 (all)		21 (all), 33 (all)	21 (all), 33 (all)		21 (all), 21.5, 21.53, 21.95, 21.97, 33 (all) 183.29
Production Approval	21 (all)	21 (all)		21 (all)	21 (all)		21 (all), 21.123, 21.125, 21.130, 21.137, 21.267, 21.289, 183.31
Operations Approval – Ground Operations							21.128, 65 (all), 138 (all)
Operations Approval – Flight Operations	91 (all), **135.43**, 135.95, 135.99, **135.145**, 139.5, **139.101**, **139.103**, 139.105, 139.107, 139.109, **139.201-217**,	91 (all), **135.145**		91 (all), **135.145**	91 (all), **135.145**		91 (all), 139.215, 145 (all)
Licensing	135.243, 135.244, 135.245, 135.247, 135.249, 135.251, 135.253, 135.255, 135.263, **135.323-353**, 420.15-17, **420.41-57**, 431.3, 431.9, 431.11-15, 431.61,431.71-75, 433.3, PART 431,PART 450	PART 431,PART 450		PART 431,PART 450	PART 431,PART 450		PART 431,PART 450
Launch Approval	420.23,	420.23,		420.23,	420.23,		
Continued Flightworthiness	23 (all), 33 (all), **91.7**,135.25, 135.71, 135.169, 135.179, 135.413, 135.443, 135.App A,	23 (all), 33 (all), 135.169, 135.179, 135.App A,		23 (all), 33 (all), 135.169, 135.179, 135.App A,	23 (all), 33 (all), 135.169, 135.179, 135.App A,		21.175, 21.182, 21.183-199, 21.221-225, 21.303, 21.305, 21.441, 21.445, 21.483, 23 (all), **91.7,91.411-415,**135.25, 135.71, 135.179, 135.413, 135.443, 135.App A, 145 (all), 183.27, 183.33
Problem Reporting & Tracking	**21.3,** 135.21, 135.63, 135.65, **135.67**, 135.69, 135.415-417, 420.61, 431.45, 431.77-79, 431.85	**21.3,** 91.187, 135.63, 135.65, **135.67**, 135.69,		**21.3,** 91.187, 135.63, 135.65, **135.67**, 135.69,	**21.3,** 91.187, 135.63, 135.65, **135.67**, 135.69,		**21.3,** 21.277, 21.293, 39, 135.63, 135.65, **135.67**, 135.69, 91.417-421,135.415-417, 135.419, 135.421-439, 43 (all), 145.43, 145.55, 145.63, 145.79, 183.17, 135.431

Aviation / Functions / RLV	Pre-Flight	Taxi & Take-off	Climb	Cruise	Descent	Landing	Maintenance
	Pre-Launch	**Launch**		**Sub-orbit / Orbit**	**Land/ Recovery**		**Maintenance**
Risk Assessment & Management	135.211, 135.365-373, 135.379-383, 420.25, 420.App A-E, 431.33-39, 431.43,,PART 450	135.181, 135.183, 135.365-373, 135.379-383, 135.389-391, 420.25,PART 450		135.181, 135.183, 420.25,PART 450	135.181, 135.183, 135.211, 135.375-377, 135.385-387, 135.393-397, 420.25,PART 450		
Safety Assurance	91.13, **91.205-211, 91.215-91.223,**91.513,91.603-613,135.73, 135.75, 135.79, 135.83, 135.85, 135.87, 135.89, 135.91, 135.93, 135.97, 135.100, 135.101, 135.105, 135.107, 135.109, **135.111**, 135.113, 135.117, 135.119, 135.120, 135.121, 135.122, 135.123, 135.127, 135.128, 135.129, 135.149, 135.150, 135.155, 135.171, **135.177**, **135.178**, 135.217, 135.219, 135.227, 135.263, 135.265, 135.267, 135.269, 135.273, 135.293, 135.295, 135.297, 135.299, 135.301, 420.59, 431.5-7, 431.33-39, 431.43-45,	91.13, 91.21, 91.107, 91.185, **91.205-211, 91.215-91.223,**91.215, 91.513, 91.603-613,135.73, 135.75, 135.79, 135.83, 135.85, 135.87, 135.89, 135.91, 135.93, 135.97, 135.100, 135.101, 135.105, 135.107, 135.109, **135.111**, 135.113, 135.122, 135.123, 135.127, 135.128, 135.129, 135.150, 135.155, 135.171, **135.177**, **135.178**, **135.180**, 135.225, 135.229, 420.59,		91.13, 91.15, 91.21, 91.107, 91.185, **91.205-211, 91.215-91.223,**91.215, 91.513, 91.603-613,135.73, 135.75, 135.79, 135.83, 135.85, 135.87, 135.89, 135.91, 135.93, 135.97, 135.100, 135.101, 135.105, 135.107, 135.109, **135.111**, 135.113, 135.122, 135.123, 135.127, 135.128, 135.129, 135.150, 135.155, 135.171, **135.177**, **135.178**, **135.180**,	91.13, 91.21, 91.107, 91.185, **91.205-211, 91.215-91.223,**91.215, 91.513, 91.603-613,135.73, 135.75, 135.79, 135.83, 135.85, 135.87, 135.89, 135.91, 135.93, 135.97, 135.100, 135.101, 135.105, 135.107, 135.109, **135.111**, 135.113, 135.122, 135.123, 135.127, 135.128, 135.129, 135.150, 135.155, 135.171, **135.177**, **135.178**, **135.180**, 135.217, 135.219, 135.221, 135.223, 135.225, 135.229, 420.59, 431.51-59,		91.513,135.171, **135.177**, **135.178**, **135.180**, 145 (all)
Mission Assurance							
Training	135.125, 420.19-21, 420.63-71, 420.App A-E, 433.5,	420.63-71			**139.315-319**, 420.63-71		135.125, **139.307-343**, 420.63-71, **145.39, 147 (all),** 183.23, 183.25
Inter- & Intra- Agency Coordination	**Part 34 (all), 135.251, 135.253, 135.255,** 13.21, **91.703, 135.43**	91.129, 91.805, 91.819, 91.821, 21.257, **Part 34 (all)**, 13.21, **91.703, 135.43**		91 Subpart I, 91.805, 91.819, 91.821, 21.257, **Part 34 (all)**, 13.21, **91.101, 91.703, 135.43**	91.805, 91.819, 91.821, 21.257, **Part 34 (all)**, 13.21, **91.101, 91.703, 135.43**		21.25, 21.29, 21.31, 21.257, **39, Part 34 (all), 21.613, 91.25, 91.609,** 183.21, 13.21, **135.323, 135.333, 139.321, 135.43**

3.6 Functional Correlation to Lessons Learned

Using the System Functions and Procedural Items allows correlation to lessons-learned derived in Section 2.1.7 for Aviation, Section 2.2.7 for STS and Section 2.3.7 for RLV. Each domain's lessons-learned is correlated to one or more functions to which it has applicability, Table 15. Subsequent work in the development of this NPRM effort will need to take these lessons-learned into account.

Table 15 Functional Correlation to Lessons Learned

System and Procedural Functions	Aviation Lessons Learned	Shuttle Lessons Learned	RLV Lessons Learned
System Functions			
1. Propulsion	AV103, AV107, AV108, AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS401, STS402, STS411, STS412, STS413, STS414	RLV204, RLV207-RLV210, RLV309, RLV405, RLV410, RLV411
2. Communication	AV56, AV59, AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
3. Navigation	AV59, AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV204
4. Flight Controls	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV204, RLV207
5. Electrical/Wiring	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS411, STS412, STS414	
6. Thermal Protection	AV151, AV301, AV304	STS301, STS302, STS304, STS306, STS307, STS310, STS311, STS412, STS413, STS414	RLV308
7. Environmental Systems	AV205, AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
8. Surveillance	AV59, AV151, AV301, AV304		
9. Software	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
10. Propellant Management	AV55, AV57, AV103, AV151, AV301, AV304	STS206, STS306, STS307, STS310, STS311, STS414	RLV211
11. Flight Safety Systems	AV151, AV301, AV304, AV310, AV318	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV201
12. Ground Support Systems	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV102, RLV202, RLV301-RLV303, RLV403, RLV404, RLV413
13. Payload/Cargo	AV57, AV151, AV301, AV304	STS301, STS304, STS306, STS307,	

System and Procedural Functions	Aviation Lessons Learned	Shuttle Lessons Learned	RLV Lessons Learned
		STS310, STS311, STS414	
14. Structures	AV151, AV301, AV304	STS301, STS302, STS304, STS311, STS414	RLV5
15. Avionics	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV311
16. Hydraulics	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV308, RLV409
17. Pneumatics	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
18…Landing/Recovery Systems	AV151, AV301, AV304	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
19. Health Monitors & Data Recorders	AV58, AV201, AV204, AV151, AV301, AV304, AV316	STS301, STS304, STS306, STS307, STS310, STS311, STS414	
20. Crew Systems	AV205, AV151, AV301, AV304, AV310	STS207, STS208, STS209, STS301, STS304, STS306, STS307, STS310, STS311, STS414	RLV5
21. Facilities	AV151, AV301, AV304		RLV101-RLV103, RLV301-RLV303, RLV403, RLV413
Procedural Functions			
1. Administration	AV1, AV2, AV51, AV54, AV55, AV56, AV57, AV58, AV62, AV64, AV65, AV202, AV203, AV251, AV252, AV253, AV307	STS107, STS108, STS110, STS112, STS306, STS307, STS401, STS402, STS406, STS407, STS408, STS409	RLV1-RLV8, RLV10-RLV15, RLV304, RLV313, RLV314, RLV414
2. Design Approval	AV52, AV101, AV102, AV103, AV105, AV106, AV151, AV152, AV153, AV154, AV155, AV156, AV251, AV323	STS109, STS110, STS201, STS301, STS302, STS305, STS309, STS310, STS415	RLV4, RLV5, RLV305, RLV306, RLV307, RLV310-RLV313, RLV315, RLV408, RLV412
3. Production Approval	AV251	STS113, STS204, STS305, STS307	RLV4, RLV5
4. Operations Approval – Ground Operations	AV53, AV58, AV59, AV106, AV201, AV303, AV307, AV311, AV312, AV323	STS2, STS3, STS4, STS106, STS109, STS110, STS112, STS113, STS310, STS401, STS402	RLV101, RLV102, RLV103, RLV301, RLV302, RLV303, RLV401-RLV404, RLV407, RLV413
5. Operations Approval –	AV53, AV58, AV59, AV106,	STS2, STS3, STS4,	RLV101, RLV207,

System and Procedural Functions	Aviation Lessons Learned	Shuttle Lessons Learned	RLV Lessons Learned
Flight Operations	AV201, AV305, AV315, AV316, AV317, AV318, AV320, AV324	STS101, STS106, STS109, STS110, STS112, STS113, STS310, STS401, STS402, STS404	RLV208, RLV209, RLV304, RLV401, RLV402, RLV407
6. Licensing	AV301, AV302, AV305	STS1	RLV4, RLV6, RLV9, RLV10, RLV103, RLV304
7. Launch Approval			RLV101
8. Continued Flightworthiness	AV102, AV104, AV105, AV107, AV108, AV151, AV152, AV153, AV154, AV155, AV156, AV201, AV251, AV301, AV302, AV303, AV306, AV307, AV308, AV311, AV312, AV316, AV322	STS104, STS105, STS106, STS113, STS303, STS409, STS410, STS411, STS412, STS413	RLV4, RLV5, RLV101, RLV313
9. Problem Reporting & Tracking	AV58, AV151, AV152, AV153, AV154, AV155, AV156, AV201, AV202, AV302, AV306, AV309	STS5, STS102, STS103, STS104, STS105, STS113	RLV5, RLV405, RLV406
10. Risk Assessment & Management	AV318	STS5, STS101, STS111, STS113, STS201, STS203, STS205-STS212, STS304, STS403, STS404	RLV3, RLV201-RLV207, RLV212, RLV213
11. Safety Assurance	AV63, AV205, AV308, AV310	STS5, STS101, STS201, STS202, STS203, STS205- STS212, STS403, STS404	RLV201, RLV212
12. Mission Assurance			RLV6, RLV9, RLV10, RLV13, RLV15
13. Training	AV313, AV314, AV319, AV321		
14. Inter & Intra Agency Coordination	AV57, AV58, AV60, AV61, AV63, AV252	STS106	

3.7 Common Issues

Common issues that affect both operations and maintenance activities have been identified that will need treatment in multiple places within the proposed requirements and guidelines.

3.7.1 Terminology

As noted earlier in the overview of 14 CFR 1, there is a need to arrive at a common set of terms that will work for RLVs that will not interfere or confuse terminology now being employed in the aviation domain or elsewhere within the space domain. During the 14 CFR 1 review, RTI began a process of identifying those terms that are overloaded and for which clarification will be needed in 14 CFR 401.

3.7.2 Compatibility with the 400-Series 14 CFRs

As noted earlier, 14 CFR 431 lays out the details of the RLV licensing process. The corresponding guidance material in AC 431.35-2 and the associated Guide from the FAA discuss the issuance of safety approvals within the licensing process. Prior to full consideration of RLV certification with complete design approval, these safety approvals can be used to ensure O&M practices are designed and followed in such a way to assure the public safety. Nothing was found in the 400-series that would preclude this type of approach.

3.7.3 Areas of Overlap

One of the difficulties with the current aviation 14 CFRs, echoed in each of the aviation reviews conducted to date, is the wide dispersion of related items and a corresponding lack of focus on particular topics. This complicates an applicant's ability to comply with the 14 CFRs and also complicates the FAA's ability to assess compliance. RTI is working to identify such areas so that care may be taken not to create the same difficulty in the RLV O&M NPRM product.

3.7.4 Design Dependencies

The aviation 14 CFRs, particularly those that specify airworthiness criteria, are highly dependent on the underlying design approach. Given the great variety in RLV concepts currently or previously pursued by both government and industry, RTI has postulated a tiered approach whereby only top-level requirements will be captured in the initial RLV O&M NPRM. Such rules will establish the need for submittal, review, and approval of appropriate O&M related data as part of the licensing process. To alleviate the FAA's need to evaluate this data on a purely case-by-case basis without benefit of design-related content in the rule itself, RTI proposes that the FAA establish either a Handbook or Advisory Circular to be used as the evaluation criteria. Ultimately, as specific technologies and approaches to RLV O&M transition from proof of concept to accepted practice, the relevant portions of the Handbook could be made into an Appendix of the corresponding 14 CFR with an appropriate reference added to make that information normative (prescriptive) text.

3.7.5 Areas Requiring Coordination

3.7.5.1 Inter-Agency Coordination

Significant work needs to be accomplished to coordinate RLV-related O&M activities with other government agencies. In particular, areas of overlap were identified with the Occupational Safety and Health Administration (OSHA), the National Transportation Safety Board (NTSB), the Federal Communications Commission (FCC), the Environmental Protection Agency (EPA), the Department of Defense (DoD), other groups within the Department of Transportation (DOT), ad the newly created Transportation Security Administration (TSA). It is likely that an interface will also be needed with the proposed Homeland Defense Agency if approved by Congress. The following sections provide a brief description of the possible interface points between these various agencies and the FAA as it relates to RLV O&M.

3.7.5.1.1 OSHA

The Occupational Safety and Health Administration (OSHA) is focused on protecting the health of America's workers. In general, the Occupational Safety and Health Act of 1970 has only been applied to workers on the ground. There have been some recent attempts by the various unions that cover the aviation industry to change this, most notably for flight attendants. Title 29 of the CFR contains parts that give OSHA the regulatory basis for many of the issues that may be applicable to operation and maintenance personnel in the RLV industry. Electrical systems, hazardous materials, egress from work site, personal protection gear, and noise exposure are some of the areas which need guidance regarding safe working conditions. In addition, there are recording requirements for incidents of worker injury that may also apply.

3.7.5.1.2 NTSB

The National Transportation Safety Board (NTSB) mission and charter covered in Title 49 of the CFR gives them the authority to investigate accidents and incidents involving all modes of transportation. Prior to AST becoming a part of the FAA, a Memorandum of Agreement (MOA) existed between the NTSB and the Office of Commercial Space Transportation (OCST) that outlined how accident and incident investigation would be accomplished for commercial space activity. This MOA was put into use during an investigation of an early Expendable Launch Vehicle (ELV) anomaly in 1993.[22] In light of the organizational changes, and in view of the expected rise in RLV activity, this agreement with NTSB needs to be revisited. A new regulatory basis may be needed to assign this responsibility to NTSB. Although NASA and the Air Force are not currently a part of accident/incident investigation team for aircraft, it may be prudent to formulate a team of NASA and Air force along with NTSB for determining recording requirements as well as for investigating accidents and incidents in order to gain from the space experience from these institutions. The roles and responsibilities of these agencies within the investigation team would have to be clearly stated so that interagency cooperation can be optimized.

3.7.5.1.3 FCC

The Federal Communications Commission (FCC) is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions. RLV communications with the traffic controllers may use the modes of communication that are regulated by the FCC. Rules for RLV communications need to accommodate FCC rules.

3.7.5.1.4 EPA

The Environmental Protection Agency (EPA) has the mission to protect human health and to safeguard the natural environment — air, water, and land.

Environmental regulations are mainly contained in Title 40 of the code of federal regulations. Topics that come under the jurisdiction of EPA that overlap with RLV operations and maintenance are emissions, pollutants, toxins, waste products from maintenance, accidents or incidents causing harm to air, water or land. Requirements for clean operation may include guidance on venting procedures and smoke.

3.7.5.1.5 Department of Defense (DoD)

DoD is responsible for many of the launches from the national ranges. Commercial RLV launch activities currently require close coordination with the DoD, since the DoD owns and controls the national ranges. Coordination for launch from these sites has to follow DoD rules. Further, DoD uses reserved airspace for military exercises. Launch parameters need to consider whether this airspace may be violated by the RLV. DoD may also act as a customer in providing payloads for RLVs to deliver to space. As with earlier parts of 14 CFR developed by AST, national security concerns will need to be considered in the operational rules.

3.7.5.1.6 DOT

RLV maintenance and operation will have to deal with a number of regulations regarding hazardous materials. Current regulations covering hazardous materials are in 49 CFR, with definition and enforcement by Department of Transportation (DOT) in the U.S. and ICAO internationally. Initial and recurrent ground transportation or multi-modal transportation of hazardous materials and radioactive materials and transportation of hazardous wastes are covered by these regulations. These regulations cover packaging, marking and labeling, and handling. There are also rules on which goods and materials should not be carried in proximity to mitigate risks of chemical reactions in case of package breech. Further, there are certain materials that are prohibited from being carried in a passenger carrying aircraft. RLV operations may need an exception to some of these rules. An intra-agency communication and regulatory framework are needed in establishing passenger safety on board an RLV.

3.7.5.1.7 TSA

Security regulations may need to be worked jointly with the Transportation Security Administration (TSA). Given the current security environment, coordination is also needed with other parts of the FAA that are wrestling with how to fully secure airports and transportation vehicles.

3.7.5.2 Intra-Agency Coordination

Intra-agency cooperation, planning, policy, and regulations from other branches within the FAA are needed in sharing modes of transportation leading to the airport; airport security concerns; air traffic control; airspace; and emergency fire and medical support. Space launch traffic; control in the terminal area; cruise; handoffs; and landing may involve working actively with both civilian and military air traffic controllers.

3.7.5.3 International Coordination

An RLV may have to pass through another country's airspace to achieve orbit/suborbit. RLVs may also have to consider alternate spaceports that may be situated in other countries, in case of emergencies. RLVs in both of these scenarios will likely need the cooperation with the traffic controllers to share the airspace with the air traffic. These activities need international communication and coordination. The United Nations has established a group called "The Committee for Peaceful Uses of Space". Additionally, an organization called Eurospace has been founded in 1962 to represent European space industry with European Space Agency (ESA) and European Union (EU). NASA and ESA hold joint conferences such as International Space flight Safety Conference to promote exchange of technical ideas. Currently there is no single technical organization to address sharing of international airspace or allowing RLVs to land in international spaceports in case of emergencies. The most likely forum to get issues of international RLV operations addressed is the International Civil Aviation Organization (ICAO), based in Montreal Canada. ICAO works to standardize aviation-related topics ranging from personnel qualifications and training to airport facilities and minimum vehicle equipage.

3.7.6 Third-Party Liability

Since RLV is an emerging industry, without the benefit of a history of incident/accident data, there needs to be certain protection afforded to the public from failures of RLVs. Since the failure rates for launch operations (ELV primarily) are still on the order of 20%, the rates for this insurance are very high. One RLV developer indicated that they were routinely quoted 1% of insured liability per flight, meaning that based on a Maximum Proposed Loss (MPL) of $5 million, the single flight insurance could be as high as $50,000. This is dramatically higher than that found in the aviation market. As the RLV O&M NPRM is formulated, attention needs to be paid to any approach that could improve the launch success rate and thus, through demonstrated performance, bring the RLV industry closer to the aviation market in terms of overall risk.

4.0 Data Analysis Conclusions

Data analysis completed to date has involved the correlation of the current aviation FARs with flight-phase, with functional areas, and with operations and maintenance. The only clearly defined gaps for which technical research and formulation is needed relates to those functions or flight phases for which there are no aviation corollaries. The experiences gained from twenty years of Space Shuttle activity will help in answering some of these issues, but will not go as far as first hoped. The Space Shuttle has truly never become a fully operational 'space truck' as it was originally billed. Significant disassembly and rework are needed between each flight to keep it flying. As the Chief Executive Officer (CEO) of one of the RLV companies vying for the X-Prize noted, "The Shuttle represents the paradigm of cost as no object. To be successful, we must operate in the mode of cost as THE object."

As this research effort proceeds with the goal of producing the basis for a workable NPRM on RLV O&M, additional data will be collected for each item not addressed in the current aviation FARs. In addition, data collection and analysis will need to be accomplished for each of the System Functions and Procedural Items to ensure consistency and accuracy for the RLV NPRM rules, and more importantly, the accompanying guidelines.

4.1 RPR Phase I Questions

While it is likely that the answers to the original RPR phase 1 questions may yet change as subsequent tasks are performed, the following represents RTI's current recommendations for answering each of the questions.

1. *How much of the existing 14 CFRs applicable to aircraft O&M can be utilized for commercial RLVs?*

   The underlying rationale for the current 14 CFRs will play a significant role in the commercial space 14 CFR content development. However, enough work has been accomplished to date to state that the existing contents of the aviation 14 CFRs (particularly 91, 43, and 65) should not be brought across with only minor wording changes. Each of these 14 CFRs relies on the existence of an approved type design, the end result of a vehicle certification process. The licensing approach currently on the books in the 400-series 14 CFRs does not lend itself to this type of an approach.

   As noted elsewhere in this report, RTI is suggesting that the FAA approach the issue of O&M in a phased approach, for example, using interaction with the NAS as a discriminator. This means that initially the O&M rules would be targeted at those RLVs operating in dedicated airspace (i.e. the current situation with coastal launch sites and well-defined special use airspace for separation and public safety issues).

RTI then suggests that specific O&M considerations associated with such dedicated operations could be accomplished with a high-level set of rules that make O&M considerations part of the licensing effort. These high-level rules would stipulate a prescribed set of O&M-related data that must be made available to the FAA for review and approval, and the linkages to the various procedural 14 CFRs that govern the outcomes of such reviews. RTI would then suggest that a detailed handbook or at most, an advisory circular, be developed to capture specific review criteria that the RLV license applicant can expect to have applied during the O&M data review. By opting for a handbook or advisory circular, the FAA would have the flexibility to evolve the O&M guidelines more easily as RLV technologies mature. This would mean that very little of the aviation-related 14 CFRs would be reconstituted into commercial space 14 CFRs at this time.

2. *What new 14 CFRs may be required to be developed?*

Most of the technologies under consideration by the RLV community are likely to require new Subchapters. For example, 14 CFR 33 provides separate sections for reciprocating and turbine engines. For commercial space, an engine related rule could provide any modifications for these two engine types necessary to cover RLVs use of them in an air-breathing environment and include rocket engines and any hybrid engines. Then a new subchapter could be built for hybrid engines, pure rocket engines and thrusters. One difficulty that this approach would create is one of ownership. In the preceding example, 14 CFR 33 is the responsibility of the Engine and Propeller Directorate in Massachusetts. It is unlikely that they have sufficient expertise on staff to address the various rocket engines and other reactive devises common to RLVs. Because of this coordination issue, RTI recommends that AST continue to maintain complete separation from the aviation FARs.

Of larger concern is the actual categorization of craft. As noted in 2.1of this report, the RLV industry is currently divided between traditional rocket and traditional airplane-type approaches. There has also been considerable discussion on the question of size, with at least one X-Prize contender planning an evolution from a three-passenger craft to a space-cab, and onto a space cruise ship. Such lofty goals beg the question of what is the proper division in RLV rules. It may be appropriate for RLVs to use mass to low-earth orbit and number of passenger as distinguishing features. Traditional aviation has always used gross takeoff weight and passenger count to distinguish between aircraft categories. These distinctions permeate the aviation regulatory structure particularly in the area of operations and crew requirements. As an example, aircraft spacing in a terminal environment is established based on aircraft size, and as history has shown, is a large safety concern due to issues of wake turbulence and basic aircraft handling characteristics. The FAA has indicated their desire to maintain a numbering taxonomy similar to that used for aviation 14 CFRs. RTI agrees that such taxonomy will work, but cautions that too much parallelism may ultimately lead to related topics being distributed across multiple 14 CFRs. This was noted as an impediment by more than one interviewee in the course of this research.

Using the aviation model and the gaps identified during this research, RTI has identified the following new Title 14 CFR parts as needed to fully address the RLV O&M arena:

421 – Safety Approval Procedures for Products and Parts
433 – Safety Approval Standards - Propulsion
439 – Flightworthiness Directives
443 – Maintenance, Preventive Maintenance, Rebuilding, and Alteration
465 – RLV Personnel Requirements – Non Flight crew
491 – RLV General Operating and Flight Rules

Note that the term certification has been avoided. Rather, the term 'safety approval' has been used to coincide with that in Part 431.

It also should be reiterated that the contents of these 14 CFRs would not be a reiteration of the aviation rules with a few words changed. In some cases, only a portion of the flight domain needs to be addressed. For example, for the RLV concepts that depend on traditional flight profiles to obtain a suitable altitude to rocket engine ignition to allow suborbital or even orbital flight to be obtained, it may be appropriate and necessary for such craft to adhere to Parts 91 or even 121 during their ascent through the NAS. In these cases, repetition of the part 91 and 121 content becomes redundant and problematic in that common rules are repeated and would have to be maintained in multiple places within the code.

3. *What regulatory safety guidelines need to be developed for this emerging industry to ensure public safety while new RLV O&M regulations are being developed?*

RTI expects that guidelines will ultimately exist for each system function and procedural area identified in Sections 1.4 and 3.1. Emphasis should be placed on those areas where there is no aviation corollary including carriage of hazardous materials, flight safety systems, thermal protections systems, shielding for orbital debris. The functional analysis preparatory work planned for as a follow-on to this effort is the starting point for drafting these guidelines.

One observation that should be made from early discussions on this topic is that public safety is protected in almost all cases where the internal occupants of the craft are also protected. The one exception to this is the presence and use of an escape system where the vehicle occupants are carried to safety, but the vehicle still crashes resulting in casualties on the ground. It should be noted that safety is typically increased by having a human operator onboard who is capable of dealing with unforeseen circumstances. In this regard, this and the next question may effectively be answered together. It should also be noted that the majority of proposed RLVs are manned projects. This again allows for a division of effort and a prioritization of rulemaking work going forward. RTI's believes that conventional flight termination systems within the more broadly-defined flight safety systems will suffice for unmanned operations. This would allow top-level rules to be written using the NASA and DoD experiences with FTS to be captured in a draft rule to answer the unmanned question, while the majority of the effort concentrates on the more complicated manned question.

4. *What is the effect on RLV O&M requirements if humans are onboard?*

The FAA has indicated that this question may be deferred since another team is working this issue. However, as noted in the preceding paragraph, it is difficult to fully separate this issue from the broader one of public safety.

5. *Can innovative practices such as the FAA's designee program be used for RLV licensing the same as it is being used in the aviation arena?*

RTI's believes that this is an area that should be deferred for the time being. Designees are prohibited from making interpretations of rules; rather they may only make findings of compliance to the rules. RTI does believe that designees will ultimately become a part of the FAA's oversight program, but consideration of this is premature at this point. Extensive information on how the designee system works is contained in two FAA Orders: 8100.8A (Designee Management Handbook) and 8110.37C (Designated Engineering Representative Guidance Handbook).

The FAA has indicated that this question was really intended to also address the need for guidance for FAA inspectors, as well as any designees. The guidelines to be developed to go along with the RLV O&M rule should serve as a starting point for specific inspection procedures. Further work needs to be accomplished in this area by looking at models such as the Airworthiness Handbook employed by FAA's Flight Standards group (Order 8300.10).

6. *What areas of research and development are required to conduct RLV O&M program that maintains the requisite level of safety?*

The FAA has asked RTI to defer this item for this initial work. However, as noted earlier, some work has already been done in this area. The Space Access work yielded a list of unique characteristics of reusable launch vehicles and for which no direct corollary to the current 14 CFR content exist.

This list served as a point of departure for identifying technology issues for which O&M regulations for RLVs are likely to be separate and distinct from those used in aviation. RTI, in the subsequent literature searches, examination of the Space Shuttle practices, and the interviews conducted to date have collapsed these issues into the following list for which extensive research is likely to be required even to formulate basic O&M guidelines:

- Hazardous Materials (cryogenic propellants, hypergolics, etc)
- Orbital Debris Management
- Orbital and Sub-Orbital Flight Phases
- Thermal Protection Systems
- Flight Safety Systems
- Health Monitors and Data Recorders

7. *What will the eligibility, knowledge, skill, experience, and medical requirements for an aerospace mechanic or repairman and how will they differ from an aviation mechanic or repairman?*

   In evaluating the current requirements for technicians, repairmen, and inspectors, it is clear that much improvement could be made over the aviation model. The suggestions offered by one of the people interviewed on the subject of training would seem to provide a good model to pursue. Specifically, the idea of a third-party accreditation for maintenance personnel should be investigated. Currency and experience requirements may be an issue due to the newness and varying types of technologies involved; an alternative set of criteria for the initial approvals may need to be identified.

4.2 Identified Gaps

The following sections discuss specific gaps that were identified in the course of performing this analysis.

4.2.1 Regulatory Models for New Technology

The FAA does not have a well-defined mechanism for the establishment of new rules for emerging technology. The traditional model used for aviation in the presence of novel design features is the creation of project specific special conditions or issue papers. These use, as a starting point, the existing rules for the type of aircraft, engine, or appliance that is closest to the proposed design. These special conditions or issue papers ultimately form a portion of the certification basis for approving the design that incorporates the new technology. Federal Aviation Regulations may ultimately be written to cover what was previously addressed via a special condition or issue paper. This work is often accomplished as a collaborative effort with industry by way of the Aviation Rulemaking Advisory Committee (ARAC).

Previous rules promulgated by AST have been procedurally focused and have been largely tied to single launch events. In contrast, regulations and guidelines for O&M of RLVs will require the definition of mechanisms for ongoing oversight, infrastructure for reviewing and approving pilot and mechanic candidates, and mechanisms for determining whether a proposed approach to O&M is adequate to ensure the public's safety. All of these items ultimately depend on the FAA understanding and regulating numerous new technologies for which there is largely no precedent. Since RLV-related technology is expected to evolve rapidly, the FAA should consider the creation of a regulatory model that will allow the O&M aspects of a proposed RLV to be evaluated; the safety-related elements to be identified and extracted in such a way as to allow a body of knowledge to be created; and finally, a way to transfer that body of knowledge into guidance for subsequent applications. Care will need to be taken to ensure that proprietary issues with any such approach are fully understood and are accounted for so as not to adversely affect an individual company or the US industry's global competitiveness.

4.2.2 Design Approval Mechanism

In the current licensing model employed by the FAA/AST, there is no explicit vehicle design approval. This is particularly problematic to defining a meaningful O&M NPRM. In both traditional aviation and the Space Shuttle examples, O&M is largely a direct result of decisions made during the design process. While it may be possible to evaluate a particular set of operational procedures or a schedule for maintenance to determine if it appears to make sense for a particular design, without approving the design or more accurately requiring that the design be proven, any such evaluation is subject to gross misjudgment. For example, traditional aviation requires that an applicant seeking FAA design approval empirically demonstrate the ability of a vehicle to land and come to a stop in a defined distance given vehicle weight, ambient air temperature, and a specific set of criteria associated with the braking mechanisms (e.g. disc brakes, thrust reversers, etc.). Without such a demonstration, the FAA would have insufficient data to evaluate the related operational procedures for landing in a variety of conditions, nor would there be a basis for determining the efficacy of a proposed maintenance approach for the vehicles braking systems.

4.2.3 Phasing and Rule Hierarchy

RTI believes that there are at least four possible mechanisms for phasing the requirements for RLV O&M. The first of these, introduced in Section 3, relates to integration of the RLV into the NAS. Three phases were identified: Special Use Airspace (SUA) (status quo where only coastal launches allowed), semi-integrated (a mix of RLV and traditional aviation where certain flight phases are still protected by additional separation measures), and fully integrated where RLV operations are routine and intermixed with traditional aviation.

The second phasing approach is to look at flight profile and distinguish between orbital and sub-orbital trajectories. Since the current RLVs in development are split across both full orbital and sub-orbital flight regimes, this phasing mechanism does not afford any relief in terms of regulatory priorities.

The third phasing approach is to look at vehicle mass. This is a clear distinguishing point between near-term RLV work and the longer-range vision. Initial work would indicate that the FAA should focus their efforts on lower mass, fewer passenger RLVs in the near-term. A distinction similar to Part 23 and Part 25 may be in order. This may also help to focus efforts in such a way as to not become overly burdensome given the FAA's differing philosophy on safety margins found in AC 23.1309-1C versus 25.1309-1A.

The fourth possible phasing mechanism relates to the business relationships that currently exist in the RLV industry versus the more mature environment of traditional aviation. At least in the near-term, it is expected that the RLV OEM and operator will be the same. This may allow for some prioritization of the requirements concerning third-party repair and the handoff of operational data/limitations between different commercial entities. Care should be taken to ensure a regulatory loophole is not created if this phasing option is taken by allowing a manufacturer to establish a sister company to capitalize on a lack of regulatory framework for third parties. This scenario is similar to the current aviation FARs (see Section 2.1.5.5) on Experimental Aircraft.

If any of these phasing options are considered to help manage the regulatory development effort, criteria should be established to allow the resulting priorities to be modified in light of new information considering the rate and direction of the RLV industry's evolution. Possible trigger points for such a reevaluation include industry activity forecasts, program announcements, accidents/incidents, significant technology advancements, or actual license applications.

4.2.4 Differing Safety Approaches

The current launch licensing process is based on the calculation of E_c, the estimated third-party casualties in the event of a catastrophic vehicle failure. E_c is the summation of products of probability of occurrence, casualty area of impacting debris, and the population density. This figure is kept low by launching from remote sites where the population density is low. Given the types of propellants involved and the forces associated with rocket propulsion, Ec provides a good way for ensuring public safety for launch operations. The regulatory requirement for Ec is 30×10^{-6} or better.

The aviation model for addressing safety is focused on the vehicle's occupants and is described in terms of effect of a failure on the vehicle, effects of the flight crew's workload, and the potential for injuries/fatalities among the vehicle's occupants. Detailed safety assessments are required by the FAA from each applicant seeking design approval of their product. The regulatory requirement governing failure conditions for aircraft states that failures that prevent continued safe flight and landing must be extremely remote. This has historically been taken to mean 1×10^{-9} or better.

While the concept of an extremely remote vehicle failure and E_c are not contradictory, the difference in how the concept of safety is addressed in the regulations may prevent approaches used in the aviation domain from being applied in a similar fashion for RLVs. This is closely related to the lack of design approval (see section 3.4.2.2).

4.2.5 Ongoing Oversight

Once a license is granted, there are many activities such as training, maintenance, and operations that require ongoing oversight. 14 CFR 431 already addresses delegation of some of these activities by way of a safety official to examine all aspects of the applicant's operations [14 CFR 431.33 (c)]. FAA/AST will need to provide oversight of these designees, as well as determine how to address activities that take place in between launches. There is also no infrastructure for enabling existing FAA resources or existing processes to be employed to accomplish such tasks (e.g., the work performed by Aviation Flight Standards). As noted earlier, it may be premature to implement a delegation system as it exists in the aviation domain may not work for the RLV domain because of questions of skill, knowledge, and experience in broad areas of technology. However, specialists in particular technology may be sought out for advice and information.

As an example of this gap, consider that RLV developers will want to have a fair amount of flexibility to be able to make design changes to their vehicles to improve safety and efficiency. 14 CFR 43 addresses alterations via requirements for various inspections and record keeping of any changes made to an aircraft. Assuming a similar rule is put in place for RLVs and putting aside the design approval issue for the moment, the FAA will need to identify whether they will be involved in such inspections, what records are required, and where such records must be kept. In the aviation domain, specific FAA forms are used to record and notify the FAA of major repairs and alterations. To whom would these notifications be sent and what would be done with them? Most importantly, are they even necessary? These questions will need to be answered to arrive at the role of AST in ongoing oversight, not just at time of launch approval.

4.3 Initial NPRM Recommendations

An RLV O&M NPRM will need to consist of both specific regulations, as well as the means to properly interpret those regulations. Toward this end, RTI is recommending that a top-level set of rules be formulated that allow for a fair amount of flexibility. This is to accommodate the wide variety of RLV concepts and flight profiles that are expected during the initial growth period of the industry. A set of guidelines would then be developed that would contain the specific approaches used for each type of design or technology. As designs mature, technology evolves, and lessons are learned, those items in the guidelines that prove to be universal and effective in improving safety could be elevated to a rule, much like has occurred in the aviation domain. The next few sections discuss specific candidates for both the initial rule and the initial set of guidelines.

4.3.1 Contents of the Rule

As noted in Section 4.1, it may be useful to use numbers that closely correspond to those used in the aviation 14 CFRs to address similar topics. However, the actual packaging is less important than the specific content of the rule. This section discusses specific items that should be part of a RLV O&M NPRM regardless of packaging.

4.3.1.1 Existence and Submittal of Maintenance Data

History has shown that by designing for maintainability, safety is often enhanced. Structure, engines, and vehicle systems are easier to troubleshoot, can be repaired more quickly, and often with a greater degree of confidence when maintenance issues are addressed during design. The FAA should impose a requirement for the provision of Instructions for Continued Flightworthiness (ICF) that addresses preventative maintenance and by way of the safety program specified in 14 CFR 431, those items that require heightened attention due to their safety-critical designation. This maintenance data should be required to be delivered as part of a license application.

4.3.1.2 Existence and Submittal of Operating Manual

Since the various RLV concepts are likely to have very unique operating characteristics (e.g., jettison of a lifting balloon at high altitude, loading of cryogenic propellants in flight, etc.), some form of detailed operating or flight manual should be required as part of the licensing application.

4.3.1.3 Safety Reporting

14 CFR 431 currently provides for reporting in the event of an accident, incident, or mishap. It does not, however, require reporting of the discovery of a potential safety problem similar to that found in 14 CFR TBD. The FAA has a responsibility for ensuring safety problems, once identified, are reviewed to determine if they are systemic thus warranting further action such as a flightworthiness directive. As noted earlier, RTI recommends that this activity is of critical importance to ensuring the public safety and warrants a similar mechanism to that of 14 CFR 39, Airworthiness Directives. For the case of RLVs, perhaps the term Flightworthiness Directives is more appropriate.

4.3.1.4 Pilot Licensing

This area is largely self-explanatory. Rocket technology is inherently dangerous when not handled properly. While the pilots of such vehicles will initially be pioneers, venturing where there is only limited precedent from which to build a reasonable and appropriate training curriculum, basic piloting skills coincident with the type of craft and its unique flight characteristics is in order.

4.3.1.5 Technician Licensing

This area is actually considerably more gray. As was noted by a couple of the individuals interviewed, the technical skills to work on RLVs tends to be quite diverse, and with the exception of the Shuttle, quite general in nature. There does not currently exist an appropriate training model that could lead to a unique RLV license for mechanics. It is suggested that any initial rule in this area use technology-independent language such as 'demonstrated skill and background commensurate with the type of work being performed.'

4.3.2 Supporting Guidance

The intent of initial RLV O&M guidelines would be two-fold. First, the guidelines could be used by industry to better understand the criteria by which their submittals will be reviewed. In other words, by clearly stating a set of evaluation guidelines and making them transparent to industry, the "bring me a rock and I'll tell you if it's the right rock" will be dispelled. The second role that these guidelines would perform is to provide a collection mechanism for information that may ultimately form the basis of new rules.

4.3.2.1 General Criteria

While RTI suggests that the initial rules for RLV O&M be written at a high level, the accompanying guidelines will need to provide specific information to allow the information submitted to the FAA to be evaluated. As an example of how this might work, consider 14 CFR 23.775, Requirements for Windshields and Windows, where the language "inherent characteristics of the material used" appears in the rule. Guidelines, which the FAA and the industry might consider developing via a consensus process, would elaborate the detailed characteristics for the specific materials used in RLV windshield. This would be similar to the approach used in aviation where many performance-based specifications have been developed in SAE and RTCA committees. This may be a natural evolutionary path for COMSTAC in its role as a Federal Advisory Committee.

By separating the rules and guidelines in this manner, the FAA retains a great deal of flexibility while still protecting the public safety. The current aviation FARs provide a number of examples of this approach.

4.3.2.2 Operational Readiness Review

This is not a new suggestion, but rather an extension of the mission readiness review concept already codified in 14 CFR 431.37. Specific guidelines should be developed that will address the readiness of the crew; ground support personnel; and air traffic personnel including any needed coordination between FAA ATC and range and/or mission control personnel.

4.3.2.3 Maintenance Readiness Review

While this could be subsumed within the overall umbrella of the mission readiness review, RTI suggests that this is better kept as a separate activity, one that should occur much earlier in the overall licensing process.

5.0 Next Steps

It is clear from this analysis, that RLV O&M regulations will need to evolve with the industry and that only the most basic rules can be formulated at this time. This section provides a brief description of the next steps in their definition.

5.1 Guidelines Development

The Guidelines discussed in Section 4.3.2 will require significant coordination with Industry. The System Functions and Procedural Items developed in Section 3.1of this report may serve as a useful taxonomy to approach the development of the guidelines. This activity will be largely dependent on the technology unique information that will ultimately result from the functional analysis (see next).

5.2 Functional Analysis Preparation

This report has served to lay the groundwork for a much more extensive effort designed to identify RLV O&M requirements and guidelines for specific system functions and associated procedures. Further work is needed to allow for a complete functional analysis to be performed on a specific RLV architecture. As part of the preparation for such a functional analysis, each system function and procedural area identified in this report needs to be examined.

Data collection focused on each system must be accomplished to identify the current state of the art, best industry practices, and unique safety considerations associated with that system. Further, a more detailed analysis of how external interfaces to RLV operations may affect these systems must be accomplished. For example, work currently underway at AST has identified limitations in the Global Positioning System (GPS) metric tracking and the Automatic Dependent Surveillance-Broadcast (ADS-B) systems that have been suggested for providing RLV surveillance capability. Since both GPS and ADS-B are considered part of the FAA's overall modernization efforts, identification of such limitations will help shape the initial O&M rules and guidelines, as well as serve as a mechanism for getting RLV issues considered by the broader FAA community.

Preparation for the functional analysis will also allow specific places where inter- and intra-agency coordination will be needed. Of particular interest, are those places where multiple approvals may be needed such as the use of dedicated aviation frequencies or other frequencies with the FCC. It will also allow for some work to be started in outlining where international coordination, with ICAO, is required, (e.g., common specifications for FSS where initiation may pose a hazard to airspace of a sovereign state).

5.3 Validation

RTI suggests to the FAA the contents of both proposed requirements and the associated guidance be validated. The means of such validation is described below.

5.3.1 Validation Via Accident and Incident Analysis

Confidence can be gained in the proposed requirements and guidance material by looking at whether or not an accident or incident would have occurred if such material had been available and complied with in advance of the event. While there is very little history established for RLVs per say, many of the technical issues have been experienced in conventional aircraft, the Shuttle, or in various demonstration programs.

5.3.2 Current/Proposed RLV Concepts Validation

FAA/AST employed a series of tabletop exercises in the validation of the RLV licensing NPRM. RTI proposes that these exercises be repeated to a limited extent once the O&M NPRM has matured to a point of draft text.

5.3.3 Validation Via Generic RLV Functional Analysis

There has been considerable discussion concerning the definition of a generic RLV that could be used to formulate not only O&M requirements, but also stipulations on basic design elements to ensure overall vehicle safety is achieved. While RTI continues to have reservations that a true generic RLV can be arrived at that will work for all of the concepts currently under consideration, an appropriate level of abstraction may be arrived at to allow validation to a 'generic' RLV model to occur.

6.0 Summary

This report has provided a collection of data and lessons-learned gleaned from the domains of aviation, government-space activities (NASA), and the nascent RLV industry. More than anything else, it has provided a roadmap for the near-term efforts to collect and synthesize all that is known on the subject of O&M from these domains for application in formulating regulations and guidelines for the commercial space RLV industry. RTI believes that the taxonomies and phased approach outlined in this report will provide the mechanism for arriving at a workable RLV O&M NPRM that ensures the public safety while continuing to allow for ongoing technological development and the fostering of a globally competitive RLV industry.

Appendix A Acronyms/Terminology

A&P	Airframe & Powerplant
A/C	Aircraft
AC	Advisory Circular
AD	Airworthiness Directive
AETB-TUFI-8	Alumina Enhanced Thermal Barrier
AFS	Aviation Flight Standards
AMF	Astronauts Memorial Foundation
ANPRM	Amended Notice of Proposed Rule Making
AOG	Airplane on Ground
APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee
ARF	Assembly and Refurbishment Facility
ARP	Aerospace Recommended Practice
ASQ	American Society for Quality
AST	Office of the Associate Administrator for Commercial Space Transportation
ASTWG	Advance Spaceport Technology Working Group
ASW	Aerospace worthiness Standards
ATA	Air Transport Association
ATAC	Advanced Technology Advisory Committee
ATC	Air Traffic Control
ATM	Air Traffic Management
ATOS	Air Transport Oversight System
ATSRAC	Aging Transport Systems Rule Making Advisory Committee
AVCS	Air Vehicle Control Station
BFE	Buyer Furnished Equipment
BCSP	Board of Certified Safety Professionals
CAA	Civil Aviation Authorities
CAM	Civil Aeronautics Manual
CAR	Code of Aviation Regulations
CASS	Continuous Analysis and Surveillance
CAST	Civil Aviation Safety Team
CDR	Critical Design Review
CEI	Contract End Item
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CIL	Critical Items List
CINCSPACE	Commander In Chief, Space Command
CMR	Certification Maintenance Requirements
COFR	Certificate of Flight Readiness
COLA	Collision on Launch Assessment
COMBO	Computation of Miss Between Orbits
COMSTAC	Commercial Transportation Advisory Committee
CONOPS	Concept Of Operations
CONUS	Continental United States
CRM	Cockpit Resource Management
CRV	Crew Return/Rescue Vehicle

DACUM	Developing A Curriculum
DARPA	Defense Advanced Research and Planning Agency
DCC	Division of Community College
DCN	Document Change Notice
DFRC	Dryden Flight Research Center
DMS	Docket Management System
DNPS	Delaware North Park Services
DoD	Department of Defense
DOT	Department of Transportation
EIS	Environmental Impact Statement
EFI	Enterprise Florida, Inc.
ELV	Expendable Launch Vehicle
EOM	End Of Mission
EPA	Environmental Protection Agency
ESMC	Eastern Space and Missile Center
ET	External Tank
ETOPS	Extended Twin (engines) Operations
FAA	Federal Aviation Administration
14 CFR	Federal Aviation Regulation
FHA	Functional Hazard Assessment
FL	Florida
FMEA	Failure Modes and Effects Analysis
FEMA/CIL	Failure Modes and Effects Analysis/Critical Items List
FMECA	Failure Modes, Effects, and Criticality Analysis
FMS	Flight Management System
FTS	Flight Termination System
FOCC	Flight Operations Control Center
FOQA	Flight Operations Quality Assurance
FRCS	Forward Reaction Control System
FRR	Flight Readiness Review
FSDO	Flight Standards District Office
FSS	Flight Safety Systems
FTD	Flight Training Devices
FTS	Flight Termination Systems
FY	Fiscal Year
G	Gravitation Acceleration at Sea Level
GOR	Ground Operations Review
GPS	Global Positioning Satellite
GSE	Ground Support Equipment
GSRP	Ground Safety Review Panel
GSS	Ground Support System
HBAT	Handbook Bulletin for Air Transportation
HCF	High Cycle Fatigue
HMI	Human-Machine Interface
HMF	Hypergolic Maintenance Facility
HTHL	Horizontal Take Off and Landing
HTVL	Horizontal Take Off and Vertical Landing
IASA	International Aviation Safety Assessment

ICA	Instructions for Continued Airworthiness
ICF	Instructions for Continued Flightworthiness
IFR	Instrument Flight Rules
ILS	Instrument Landing System
ISS	International Space Station
IVHM	Integrated Vehicle Health Monitoring
IV&V	Independent Validation and Verification
JAA	Joint Aviation Authorities
JAR[1]	Joint Airworthiness Regulations
JAR[2]	Joint Aviation Regulations
JAR-VLA	Joint Aviation Regulations-Very Light Airplanes
JROC	Joint Requirements Oversight Council
Klb	Kilo Pound
Klbs	Kilo Pounds
KSC	Kennedy Space Center
LA	Los Angeles
LCC	Launch Control Complex
LOA	Letter of Agreement
LEO	Low Earth Orbit
LLC	Limited Liability Corporation
LRCS	Long-Range Communication System
LRU	Line Replaceable Units
MAKS	Multi-Purpose Aerospace System
MMEL	Master Minimum Equipment List
MEL	Minimum Equipment List
MLP	Mobile Launcher Platform
MNPS	Minimum Navigation Performance Specifications Airspace
MRB	Maintenance Review Board
MRM	Maintenance Resource Management
MRO	Maintenance, and Repair, Overhaul
MSG	Maintenance Steering Group
MSI	Maintenance Significant Items
MSL	Mean Sea Level
N/A	Not Applicable
NAI	National Aerospace Initiative
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NAT	North Atlantic
NIDA	NIDA Corporation
NOTAM	Notice To Airmen
NPRM	Notice of Proposed Rulemaking
NSP	National Simulator Program
NSLD	NASA Shuttle Logistics Depot
NSTS	National Space Transportation System
O&M	Operations and Maintenance
O&S	Operations and Supportability
OEI	One Engine Inactive
OEM	Original Equipment Manufacturer

OMD	Operations and Maintenance Document
OMDP	Orbiter Maintenance Down Period
OMI	Operations and Maintenance Instructions
OMRS	Operations and Maintenance Requirements Specifications
OMRSD	Operations and Maintenance Requirements Specifications Document
OMS	Orbital Maneuvering System
OPF	Orbital Processing Facility
ORR	Orbiter Readiness Review
OSD/AF	Office of Scientific Development/Air Force
OSHA	Occupational Safety and Health Administration
PiC	Pilot in Command
PMA	Parts Manufacturer Approval
PMI	Principle Maintenance Inspectors
PoC	Point of Contact
PRACA	Problem Reporting and Corrective Action
PRR	Payload Readiness Review
PSRP	Payload Safety Review Panel
Pt.	Part
RCM	Reliability Centered Maintenance
RLV	Reusable Launch Vehicle
RNAV	Area Navigation
RPM	Revenue Passenger Mile
RPR	Rulemaking Project Record
RPSF	Rotation, Processing & Surge Facility
RSO	Range Safety Officer
RSRM	Reusable Solid Rocket Motor
RTI	Research Triangle Institute
RTS	Return To Service
RTV	Room Temperature Vulcanizing
RVT	Reusable Vehicle Test
SAE	Society of Automotive Engineers
SDP	Safety Data Package
SDR	Service Difficulty Report
SFE	Supplier Furnished Equipment
SGS	Space Gateway Support
SIAT	Shuttle Independent Assessment Team
SLF	Shuttle Landing Facility
SLI	Space Launch Initiative
SME[1]	Shuttle Main Engine
SME[2]	Subject Matter Expert
S/N	Stock Number
SNPRM	Supplemental Notice of Proposed Rule Making
SOP	Standard Operating Procedure
SPST	Space Propulsion Synergy Team
SRB	Solid Rocket Booster
SRD	Systems Requirements Document
SRSO	Senior Range Safety Officer
SSA	System Safety Assessment
SSME	Space Shuttle Main Engine

SSP	Space Shuttle Program
SSTO	Single Stage To Orbit
SSV	Space Shuttle Vehicle
STS	Space Transportation System
SUA	Special Use Airspace
SUP	Suspected Unapproved Parts
TAL	Transoceanic Abort Landing
TBD	To Be Determined
TCAS	Traffic Alert and Collision Avoidance System
TOGA	Take-Off/Go-Around
TPS	Thermal Protection System
TSA	Transportation Security Administration
TSO	Technical Standard Order
TSOA	Technical Standard Order Authorization
UAV	Unmanned Aerial Vehicle
US	United States
USAF	United States Air Force
USBI	United States Boosters, Inc.
USC	United States Code
VAB	Vehicle Assembly Building
VFC/MFC	Maximum Speed For Stability Characteristics
VDF/MDF	Demonstrated Flight Diving Speed
VFR	Visual Flight Rules
VOR	Very High Frequency Omni range Station
VSP	Vision Spaceport Program
VTHL	Vertical Take Off and Horizontal Landing
VTVL	Vertical Take Off and Landing
WSMC	Western Space and Missile Center
WWI	World War 1
Wx	Weather

Appendix B List of Considerations

The original List of Considerations is presented below. While some work has been accomplished on most of these topics, RTI does not consider any of them complete at this time.

Regulatory Considerations:

The review of aviation community data for the purpose of identifying lessons-learned should include:

1. Review of all applicable 14 CFRs

2. Review of history of 14 CFRs, accidents, NTSB recommendations, Airworthiness Directives (ADs), Reliability Centered Maintenance (RCM)

3. RLV approval and airworthiness considerations as currently done for commercial aircraft (what's applicable and what's not)

4. Compatibility with other 14 CFR parts

5. Potential use of designees in the O&M area

6. Qualification standards of personnel performing inspections and maintenance and operations functions. This would include both initial and recurrent training.

7. In cases where RLV shares resources that already have rules for aircraft (airports, approach procedures, ATC support, etc), a collaborative understanding must be established between the various FAA branches.

8. Insurance and financial implications

9. Accident and incident reporting requirements

10. Emergency situations in airport environment

Procedural/Process Considerations:

1. Inspection procedures, schedules, criteria and maintenance procedures commensurate with the use and safety characteristics of the components of RLV in all phases of the mission

2. Pre-flight operational testing and checkout during countdown

3. RLV Launch, Re-entry and Landing Commit Criteria

4. Rules for development of operational procedures (how much spacing should be allowed between RLV and other aircraft, how much runway time should be reserved for RLV, ATC to RLV communications, etc)

5. Collaborative handoffs between mission control and ATC

6. Implication of private citizen passengers

7. Passenger training (in addition to pilot training, maintainer training etc) issues and passenger medical certification issues

Hardware Considerations:

1. Review of STS incidents/accident and lessons learned for maintenance and operation

2. Payload and vehicle safety issues

3. The role of safety devices in the O&M philosophy for RLVs

4. The role of Flight Safety Systems (FSS) including Flight Termination Systems (FTS) in the O&M philosophy for RLVs Including:
    a. Autonomous FSS versus Standard Command Type FSS
    b. Use of vehicle onboard systems as FSS or FSS components
    c. Hybrid Systems such as combinations of FSS and no FSS on certain stages during flight
    d. FSS versus No FSS at all
    e. FSS with manned personnel (override)
    f. Space based FSS

5. Contingency abort systems reuse (how many times, refurbishment, criteria that must be satisfied before re-flight, etc.)

6. Propulsion System reuse (how many times, refurbishment, criteria that must be satisfied before re-flight, etc.)

7. Navigation, Guidance and Control (same as propulsion)

8. Reentry and Landing System reuse (how many times, refurbishment, criteria that must be satisfied before re-flight, etc.)

9. Critical safety systems refurbishment, re-testing and number of flights before replacement

10. Determine applicable Aircraft maintenance and operational activities that apply directly to RLVs

11. Applicability of the Minimum Equipment List (MEL) concept for RLVs

12. Provision and maintenance of safety devices and sustenance and comfort equipage for humans on board

Appendix C Past and Current RLV Concepts/Programs

The following table provides a summary of prospective RLV concepts. They are categorized as: X-Prize Entrants, U.S. Government/Industry Partners, Start Up Commercial Concerns, and Hobbyists/Fully Experimental/Other.

REUSABLE LAUNCH VEHICLES – X-Prize Entrants					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
Advent Launch Systems (2)	Houston, Texas	Advent Mayflower	VTHL	Active	Water Takeoff and Landing
Aeroastro LLC	Herndon, Virginia	PA-X2	VTHL	Active	Parafoil Landing
Badgero and Associates	USA	Lucky Seven	VTHL	Active	Parafoil Landing using GPS
Bristol Spaceplanes LTD (2)	United Kingdom, Bristol, England	Ascender (Spacecab and Spacebus to follow)	HTHL	Active	Conventional Runway
Canadian Arrow	Ontario, Canada	Canadian Arrow	VTVL	Active	Ram Air Balloon Transition to Three Main Chutes –Water Landing (chute water landing for both stages)
Cerulean Freight Forwarding Company	Oroville, Washington	Kitten	HTHL	Active, company restructured	Conventional Runway
Cosmopolis XXI Suborbital Corporation	Moscow, Russia	C-21 (C-XXXI)	HTVL	Active	2-phase: Lifting body glide and then parachute touch down
Discraft Corporation	Portland Oregon	The Space Tourist	HTHL	Active	Conventional Runway, Disc with fixed angle take off and flared landing
DaVinci Project	Canada	DaVinci	VTVL	Active	Ballute slows descent and Parafoil for landing
Flight Exploration	United Kingdom	The Green Arrow	VTVL	Active	Parachute Landing
Earth Science Transport System	Highlands Ranch, Colorado	Unnamed	Undisclosed		
Funtech Systems (3)	Orlando, Florida	Aurora	HTHL	Active	Conventional Runway, Glide Descent
Kelly Space and Technology	San Bernardino,	Eclipse Astroliner	HTHL	Active, Teamed with	Conventional Runway, 747

REUSABLE LAUNCH VEHICLES – X-Prize Entrants					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
(Private)	California			Voight Aircraft to further develop concept	Towed then Glide Descent
Lone Star Space Access Corporation	Houston, Texas	Cosmos Mariner prototype single stage launch vehicle	HTHL	Active	Conventional Runway
Pablo De Leon & Associates	Buenos Aires, Argentina	Gauchito (The Little Cowboy)	VTVL	Active, Scaled capsule test from 32km	Parachute landing both stages
Pan Aero, Inc.	Washington DC	XVAN2001	HTVL	Active	Conventional Runway, Engine Restart to Powered Landing
Pioneer Rocketplane, Inc. (Private)	Ann Arbor, Michigan	Pathfinder	HTHL	Active, awarded a phase one contract for the Defense Advanced Research Projects Agency's Responsive Access, Small Cargo, Affordable Launch program.	Conventional Runway, Turbo fan powered takeoff to load LOX
Scaled Composites, LLC	Mojave, California	Proteus	HTHL	Already flying, System may be on hold until the X-Prize is fully funded or another team arises as a serious threat to win	Air Launch and Powered Landing
Starchaser Industries	United Kingdom, Cheshire, England	Thunderbird	VTVL	Active	Jet Powered Vertical Takeoff, Parachute recovery for both stages
TGV	Bethesda, Maryland	Michelle-B	VTVL	Raising Funds, Needs $50m	Vertical/Soft Landing With Reduced Engine Power

U.S. GOVERNMENT/INDUSTRY PARTNERS					
AGENCY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
NASA	Kennedy Space Center	Space Transportation System	VTHL	Aging Fleet	Partially Reusable
NASA/ Lockheed		X-33 Venture Star (Reusable 1-Stage, Lifting body)	VTHL Pilot less	Failure of composite H2 tanks caused severe delays. This plus various other problems caused significant overruns and the project was canceled. NASA: invested $912 million Lockheed Martin: invested $356 million	Vertical Takeoff Glide Landing
NASA/Orbital Sciences		X-34 (Reusable 1-stage suborbital)		Canceled after cost growth due to significant late hardware changes. These came after the Mars Lander failure led to review of all major NASA programs. NASA: $205 million expended on the X-34 project	Dropped from carrier plane
NASA/Boeing		X-37 (Reusable, unmanned, space vehicle)		Joint program of NASA & Air Force. However, the AF recently decided not to provide more funding after the current X-	Test various technologies and applications of space maneuvering vehicle for military and civilian uses

U.S. GOVERNMENT/INDUSTRY PARTNERS					
AGENCY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
				40 tests finish. NASA will apparently continue with the program through one space flight test.	
NASA		X-38 (Reusable lifting body)		Several successful low altitude drop flights. Budget overruns in ISS program, however, have postponed the Crew Return/Rescue Vehicle (CRV). Negotiations to continue the program with European funding are apparently on going.	Autonomous re-entry & landing Prove technology for space station CRV Para-foil Landing. Carried to orbit by shuttle. Test flights via B-52 drop.
USAF		X-40A (85% scale version of X-37)		Several drop landings succeeded and more scheduled.	Test autonomous landing, parafoil, and other technologies needed for X-37
NASA/ Microcraft		X-43A (Unpiloted 2-stage suborbital)		First flight failed due to failure in the Pegasus booster. Schedule for further flights depends on review board findings.	Dropped from carrier plane, Pegasus booster releases hypersonic non-recovered vehicle
USAF/ Starcraft Booster, Inc.		USAF		Active	
USAF/ McDonnell Douglas		DC-X/DCXA (Low altitude vehicle that	VTVL	Started as a project in the Missile Defense	Single Stage, Vertical takeoff and landing.

U.S. GOVERNMENT/INDUSTRY PARTNERS					
AGENCY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
		tested low cost reusable technologies and operations)		program. After 5 flights transferred to NASA. Demonstrated that a rocket vehicle could be flown by a small team and turned around between flights in 26 hours. All goals met but vehicle lost when leg failed to deploy on landing.	
		X-15 Reusable rocketplane		Of Historical Interest: Very successful program. Nearly 100 flights made over a decade. Big influence on the X-20 Dynasoar program and later the shuttle	Dropped from B-52. Learned how to deal with transition from atmosphere to near vacuum region and with the high temperatures on reentry

START UP COMMERCIAL CONCERNS					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
Kistler Aerospace		K-1	VTVL	Needs private funds to launch in Woomera, Australia	Parachute Landing, Airbag Cushion
Rotary Rocket		Roton	VTVL	Liquidated, Needed $120M to get operational	
Vela Technology Development		Space Cruiser/ Space Lifter System 2-Stage suborbital (2 pilots & 6 passengers for SpaceCruiser, 2	HTHL	Never publicized any hardware tests, so it seems the project, if not canceled, is in	

START UP COMMERCIAL CONCERNS					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
		pilots for SpaceLifter)		permanent limbo	
Armadillo Aerospace		VTVL Lander	VTVL	Active, Not officially a X Prize competitor, although they may purse the competition if their VTOL development progresses well.	
JP Aerospace		Darksky Station		Active	loft launch system to an altitude of 100,000 feet by balloon
Venture Star (Lockheed Seed)		Venture Star	SSTO, VTHL		
Third Millennium Aerospace		MMI Launch Vehicle			
Starchaser	UK	SHARP 1 – 5			Parachute Recovery
Space Access		SA-1	HTHL	Active	
XCOR	Mojave Desert	Rocket Plane	HTHL	Active	Conventional Runway

HOBBYISTS/FULLY EXPERIMENTAL/OTHER					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
	Russia	Angara Heavy Lift Russian Launch Vehicle			
Russian Central Research Institute of Machine Building	Russia	Norma			Partially Reusable STS
	Russia	Buran Space Shuttle			
Russian Molniya Scientific Production Association/ Zhukovskiy Central Aerodynamics Research Institute	Russia	Multi-Purpose Aerospace System (MAKS)			
	Russia	Spiral Winged Spacecraft			

HOBBYISTS/FULLY EXPERIMENTAL/OTHER					
COMPANY	**LOCATION**	**VEHICLE NAME**	**FLIGHT PROFILE**	**STATUS**	**NOTES**
	Russia	EPOS Reusable Winged Spacecraft			
	Russia	BOR Reusable Winged Spacecraft			
Russian Space Agency	Russia	TU-2000 SSTO With the Orel R&D Program			
ISAS	Japan	RVT (Reusable Vehicle Test)	VTVL	Project of ISAS, the smaller of the two Japanese space agencies.	Single Stage, Vertical takeoff and landing,
Japanese Rocket Society	Japan	Kankoh-Maru	VTVL		
	German	Hopper Reusable lifting body. 7m long, 3.8m wingspan, 1200kg		German project. Funding approved. First flight test at end of 2003.	Intended for drop tests like X-38 & X-40. Prepare for orbital Phoenix vehicle.

Note: Information on RLVs efforts currently planned or underway is extremely fluid. RTI's primary focus for the initial O&M work is on those RLV concepts that are actively funded and have a defined schedule. However, every effort will be taken to ensure novel technologies arising from the work of the hobbyists and pure R&D efforts are catalogued so that they may serve as test cases for the flexibility and completeness of the resulting regulations.

Appendix D 14 CFR Review Results (under separate document)

The following tables (see separate document) provide the detailed review results for the 14 CFR reviews conducted for this research effort to date. As noted in Section 4, additional 14 CFR reviews are planned in subsequent research phases.

The first table provides the overall list of 14 CFRs administered by the FAA along with the planned review phase based on the current definition of the O&M RPR work. The subsequent tables provide the review details for each Phase I 14 CFR in turn. They consist of paragraph number, title, summary of contents, and any notes or questions raised as to how that paragraph might apply to RLVs. Please note that the intent of this review was not to identify what would need to change in the 14 CFR to make it applicable to RLVs, but rather to understand the intent of the 14 CFR so that a determination could be made as to whether the underlying issue the 14 CFR was trying to address applied to RLVs. For purposes of administration, it is assumed that a separate and distinct set of O&M RLVs will be created rather than modifying the 14 CFRs that are already in place for traditional aviation.

Note: As these tables are used in guiding the remaining data analysis and synthesis activities, they may be updated with additional notes and questions. In other words, these tables were designed as a tool to be used throughout the NPRM effort. In a few cases, initial data capture is not complete; specifically a first pass for 14 CFRs 13 and 23 has not been completed. As noted earlier, additional 14 CFRs will also be added for the initial RPR Phase 1 effort, most notably 14 CFRs 25 and 121.

Appendix E Interviews

This section contains both the survey instruments and the raw results of the interview process. Lessons-learned from these interviews are summarized earlier in the report.

Interview Questionnaires

The following pages present the basic checklists that are being used to interview Subject Matter Experts (SMEs) in each of the areas covered by this report. These checklists were designed to be used solely as a tool to guide the discussion. Interviewers were encouraged to amend and extend these checklists as needed to identify additional lines of inquiry that might add value to the effort.

Questionnaire 1: Aviation Operations

Conduct the following survey with an objective to understand operation and maintenance activities. Compare current activities with what the industry will do even if the FAA does not impose any regulations. Also find out what specific regulations are seen as non-value added.

1. What operation activities are important for the safety (and environmental considerations) of:
    a. Pilots
    b. Passengers on your aircraft
    c. Public on the ground
    d. Flying public on other aircraft
2. What level of experience, knowledge and skills would you expect in your pilots?
3. What is your initial training program?
4. What is your plan to keep up with training as technology evolves?
5. What do you expect from a school that trains these pilots?
6. What type of record keeping activities would you expect?
7. Do any of your procedures get clumsy and non economical in trying to fit the FAA requirements? Elaborate.
8. What procedures do you use (that are not in the 14 CFRs) in order to streamline your work and adding to safety?

9. Do you know of instances of a company being penalized for not following FAA regulations while their process was what you believed to be the "right" process for safety?

10. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

11. What is your plan for keeping up with the evolving technology?

12. Do you have certain triggers that will prompt you to take a second look at your procedures?

Questionnaire 2: Aviation Maintenance

Conduct the following survey with an objective to understand operation and maintenance activities. Compare current activities with what the industry will do even if the FAA does not impose any regulations. Also find out what specific regulations are seen as non-value added.

1. What activities are important for the safety (and environmental considerations) of:

    a. Your pilot

    b. Passengers on your aircraft

    c. Public on the ground

    d. Flying public on other aircraft

2. What level of experience, knowledge and skills do you expect in your mechanics?

3. What is your initial training program?

4. What is your plan to keep up with training as technology evolves?

5. What do you expect from a school that trains these mechanics?

6. What type of repair facilities do you expect for a quick turnaround of the aircraft?

7. What type of safety processes do you impose on repair facilities?

8. What inspection do you impose on

    a. The mechanics

    b. The repair stations

9. What type of record keeping activities do you expect?

10. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

11. What are your criteria for safety in repair?

12. How do you determine that an aircraft is properly serviced and can be returned to service?

13. How do you determine the periodicity of preventive maintenance?

14. How do you determine the minimum list of equipment that must operate correctly for safety of flight?

15. How do you assure safety of flight?

16. How do you determine that repairs are needed? What kinds of inspections do you impose to find problems in this newly emerging experience?

17. What portions of the aircraft do you inspect before every flight? After every flight?

18. If you were the designer, what types of analysis would you use in design to help with maintenance such as ease of repair, frequency of inspections, repairs and replacements?

19. What types of analyses do you recommend if your repair or alteration changed the original design?

20. What types of security precautions do you take in hiring your mechanics and checking integrity of your repair stations?

21. How do you measure the quality of a part as "usable"?

22. How do you prevent some one from using a rejected part?

23. How do you plan to keep communication links between various people in your team namely a pilot who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem.

24. Do any of your procedures get clumsy and non economical in trying to fit the FAA requirements? Elaborate.

25. What procedures do you use (that are not in the 14 CFRs) in order to streamline your work and thus adding to safety?

26. Have you ever been penalized while your process was what you believed to be the "right" process for safety?

27. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

28. What is your plan for keeping up with the evolving technology?

29. Do you have certain triggers that will prompt you to take a second look at your procedures?

Questionnaire 3: RLV Interview Questions

1. What RLV technologies that you use are common to aircraft industry?

2. What equipment/technology is unique to RLVs?

3. Which of your RLV operations and maintenance (O&M) procedures are common with the aircraft industry?

4. Which parts of your O&M activities are peculiar to RLVs only?

5. Have you considered the need to change your maintenance activities to keep up with the evolving technology? How do you address them?

6. Do you have certain triggers that will prompt you to take a second look at your current procedures?

7. List the activities that your company will do even if the FAA does not impose them - in the current remote area operations and in the future populated area operations (if you are planning on future launches from or over flights of populated sites)

8. What activities do you consider most important to assure safety of:

    a. Your pilot

    b. Passengers

    c. Public on the ground

    d. Flying public on other aircraft/RLV

9. What level of experience, knowledge and skills would you expect in your mechanics?

10. What would be your initial training program, noting that you unlikely to find "experienced RLV mechanics"?

11. How do you plan to keep up with training as technology evolves?

12. What would you expect in a school that trains these mechanics?

13. What type of repair facilities do you expect for a quick turn around of the RLV?

14. What type of safety processes do you expect in your repair facilities?

15. What inspection do you impose on

a. The mechanics

b. Third party vendors

16. What type of records do you keep to help you in assessing/assuring safety of repairs as well as to investigate any future incidents?

17. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

18. What are your criteria for safety in repair?

19. How do you determine that an RLV is properly serviced and can be returned to service?

20. How do you determine the periodicity of preventive maintenance?

21. How do you determine the minimum list of equipment that must operate correctly for safety of flight?

22. How do you assure safety of flight?

23. How do you determine that repairs are needed? What kinds of inspections do you envision to find problems as the industry matures?

24. What portions of the spacecraft would you inspect before every flight? After every flight?

25. What procedures do you envision your routine RLV operation to work seamlessly with the ATC operations?

26. What elements of analysis do you use from design to help you with frequency of inspections, repairs and replacements?

27. What types of analyses do you recommend if your repair or alteration changed the original design?

28. Do you plan to use parts manufactured in foreign nations?

29. What types of security precautions do you take in hiring your mechanics and checking integrity of third party vendors?

30. Do you plan to use parts manufactured for the aircraft industry?

31. Do you plan to use parts manufactured for the automobile industry?

32. How do you measure the quality of a part as "usable"?

33. How do you prevent some one from using a rejected part?

34. How do you plan to keep communication links between various people in your team namely a pilot who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem.

Questionnaire 4: Shuttle Interview Questions

1. What STS technologies that you use are common to aircraft industry?

2. What equipment/technology is unique to the STS? What are operations are unique to the STS?

3. Which of your STS operations and maintenance (O&M) procedures are common with the aircraft industry and commercial RLV concepts?

4. Which parts of your O&M activities are peculiar to the STS only?

5. Have you considered the need to change your maintenance activities to keep up with the evolving technology? How do you address them?

6. Do you have certain triggers that will prompt you to take a second look at your current procedures?

7. What activities do you consider most important to assure safety of:

    a. Your Crew

    b. Mission Specialist

    c. Public on the ground

    d. Flying public on other aircraft/RLV

8. What level of experience, knowledge and skills do you expect in your mechanics?

9. What is your initial training program, noting that you are unlikely to find "experienced STS mechanics"?

10. How do you plan to keep up with training as technology evolves?

11. What is your training pipeline for crew/mission specialists and maintenance technicians?

12. What type of repair facilities or procedures do you think could carry over to commercial RLV maintenance operations?

13. What processes or improvements were instituted to provide a quicker reconstitution of the STS for it's next launch?

14. What type of records do you keep to help you in assessing/assuring safety of repairs as well as to investigate any future incidents?

15. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

16. What are your criteria for safety in repair?

17. How do you determine that the STS is properly serviced and can be returned to service?

18. How did you determine the periodicity of preventive maintenance?

19. How did you determine the minimum list of equipment that must operate correctly for safety of flight?

20. How do you assure safety of flight?

21. How do you determine that repairs are needed? What kinds of inspections do you envision to find problems as the STS matures?

22. What portions of the STS are inspected before every flight? After every flight?

23. What procedures, if any, do your routine STS operations use to work seamlessly with the ATC operations?

24. What elements of analysis did you use from design to help you with frequency of inspections, repairs and replacements?

25. What types of analyses would you recommend if your repair or alteration changed the original design?

26. Do you use parts manufactured in foreign nations?

27. What types of security precautions do you take in hiring your mechanics and checking integrity of third party vendors?

28. Do you use any parts manufactured for the aircraft industry?

29. Do you use parts manufactured for the automobile industry?

30. How do you measure the quality of a part as "usable"?

31. How do you prevent some one from using a rejected part?

32. How do you plan to keep communication links between various people in your team namely a crew member who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem.

33. What procedures do you use (that are not in the 14 CFRs) in order to streamline your work and adding to safety?

Questionnaire 5: Insurance

We are currently engaged in a research project for the FAA (AST division) concerned with operations and maintenance of Reusable Launch Vehicles (RLVs). In the course of this research, a number of articles, as well as interviews with RLV developers, have indicated that rulemaking by the FAA will aid in their ability to purchase third-party insurance. Based on this, we have expanded our effort to explore the criteria that underwriters use in determining insurability of RLVs. The following questions are designed to guide this exploration. Please feel free to expand or reframe the questions as you deem appropriate to aid in answering the fundamental question of "how does FAA regulatory action enable or hinder the issuance of insurance to the nascent RLV market?"

1. Do you currently, or have you in the past, insured RLV developers/operators for third-party liability?

2. If yes, can you describe some of the issues that were looked at to determine insurability and the extent of coverage provided?

3. Does third-party liability coverage extend to any sanctioning government body, e.g., the Federal Aviation Administration?

4. Thinking about the parallels with the aviation industry where third-party liability may be granted for persons on the ground under a flight path, to what extent does the FAA-required certification process impact the insurance rates, both directly and indirectly?

5. How is risk distributed for RLV developers given that there are so few of them?

6. If the FAA were going to impose requirements on vehicle maintenance, what factors would an insurer like to see included in such requirements to ensure risk is managed?

7. Same question for operational rules, both for ground and flight operations?

8. What do you see as the key factors needed to "normalize" the risk associated with RLVs, i.e., what technical advances, or how many participants for risk-sharing, etc.?

9. At what point will you consider RLV operations to be "routine" for relaxing insurance rules/coverage?

10. What would be the differences for “developmental” insurance coverage and passenger-carrying RLVs?

Interview Synopsis

Aviation 1: FAA Flight Standards Personnel Interview

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

1. What regulations are difficult to follow for the industry? Which regulations do they misunderstand on a routine basis?

   FAA regulations have a good basis (time tested).

   FAA has the statutes in the administrator making rules for safety considering the difference between air transport and air commerce. FAA requires Economic Authority Certification and the Operating Certificate to operate. Maintenance regulations are in parts 121 (Design leading to maintenance policy), 135 (design leading to maintenance policy) and in parts 21 (alteration), 43 (maintenance) and part 91 (operation -determination airworthiness by operator). Air carrier is responsible for the maintenance policy. Often some of the industry (mainly small air carriers) mistakes the manufacturer's maintenance policy to be their maintenance policy. Manufacturer has the minimum policy; air carrier needs to augment that policy.

   Another confusing term is "Major" and "Minor". The term as defined in Part 1 is very broad and ambiguous. There is a move to define these terms more accurately. Major repairs and alterations require more attention than minor repairs and alterations. Repairs assessment rule stops air carriers from grouping a number of minor repairs.

   There was much confusion in the use of approved parts. Because of heightened awareness, this is no longer a common problem.

   Record keeping is occasionally not good - problem with incomplete records.

   If regulations are misunderstood, there are a lot of checks in the system. There are three checks for all flight critical repairs - one by the repairman, second by the required inspection, and then for return to service. Even if the repairman is not trained/certificated, the people who sign off have to be. The requirement is also for "competent" not "trained".

   There are many checks in the system that contribute to safety:

   Continuing analysis and surveillance system is used to measure the effectiveness of a maintenance program and correct any inefficiency (records will tell if the program is ineffective). Keep in mind that not all incidents are real emergencies-most of the time they are just precautions since a lot of systems have backup and redundancy.

FAA from the maintenance point of view is involved in inspecting records, airplane, flight test (observation), and spot checks. Whenever there is an unscheduled maintenance, FAA may opt to do the spot check. In an ideal world, effective scheduled maintenance should be all that is required. But, an air carrier may want to use a part until it fails. There is also a connection between the pilot procedures and maintenance, which is also observed and corrected if, need be. Air carriers use MSG3 to develop a maintenance program for parts that do not yet have service data. This is based on best guess. Reliability Centered Maintenance is also followed in some cases.

2. Cultural differences between regulators and industry-Regulations say "what" is expected and industry has to know "how" they will comply. In your opinion what is the best way to see that the regulations are followed?

   Do not know if this can be helped. There are conferences and organizations that help with best practices so that air carriers learn from each other.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   Regulations help make a level playing field, prevent chaos, and there are no incentives other than moral obligation for the industry because of the insurance.

4. Synopsis of current practices:

   Air carriers design and direct the maintenance policy. Repair shops just follow the air carrier's manuals.

   Air carrier (not the repair shop) has the following nine responsibilities for maintenance:

   a. Air worthiness responsibility

   b. Maintenance manual

   c. Maintenance organization

   d. Maintenance schedule

   e. Maintenance record keeping

   f. Procedures for maintenance and alteration

g. Contract maintenance for whole aircraft or for particular parts and systems

h. Continuing analysis and surveillance

i. Training of personnel and recurrent training (look for a new advisory circular)

5. Does the industry understand the intent behind the regulations or are the regulations followed blindly?

   Industry, in general, understands the intent behind the regulations.

6. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   Use of plain language

   Simplify organization

   Separate regulations clearly for air carriers and small operators

   Currently it takes a lot of experience and time to fully comprehend the regulations. There is a systematic way in which the regulations were constructed, but it is not easily recognized.

Aviation 2: Flight Safety Foundation Safety Auditor

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

1. What regulations are difficult to follow for the industry? Which regulations do they misunderstand on a routine basis?

   There are two classes: misunderstandings and misinterpretations. Some examples are:

   a. Side facing seating arrangement in corporate aircraft. Operators do not understand that it is their responsibility to enforce seat belt rules.

   b. Minimum Equipment List -misinterpretation of full responsibility Documentation by the operators is not adequate.

   c. Misunderstanding of management of cockpit checklists- Operators (especially the small/medium sized companies) do not spend the money to get the manufacturer's checklists. They make up their own, sometimes using generic checklist from a training organization, which may not be compliant with the cockpit configuration. Small/medium sized operators often do not have an effective checklist program.

   d. Manufacturer's manuals (from both operations and maintenance point of view) are not all of the same quality; some (large companies) are better than others. Some are weak and minimally effective.

   e. No operating manual or not a well written operating manual

   f. No Standard Operating Procedure (SOP) or not a well written SOP

   g. Tool calibration problems - small/medium operators often do not have a tool calibration program.

   h. Fuel quality assurance - some operators do not know that it is their responsibility.

   i. Operators often do not consider expired parts (life-limited parts which have past their expiration time) to be of the same status as a bogus part. Operator liability is not well understood.

2. Cultural differences between regulators and industry-Regulations say "what" is expected and industry has to know "how" they will comply. In your opinion what is the best way to see that the regulations are followed?

   a. There are not enough guidance type of documents that are known to the operators - AC and inspector's handbooks. Education is needed.

b. Certain jobs such as quick turnaround need a management guide (perhaps an Advisory Circular). There needs to be a reasonable approach on what the expectations are and what the limitations are. Operators take care of what they call "Killer" items -items that are most safety critical. Return to service rules for operations are not clear.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   Operators will not operate the same way without regulations. There is a big variation in the field even with regulations. Audit items vary between operators. There is a "let us do our job our way" - a cowboy philosophy that is pervasive. There is no standard way of doing their job even with the regulations.

4. Synopsis of current practices:

   No standard way of doing their job.

5. Does the industry understand the intent behind the regulations or are the regulations followed blindly?

   In general the industry not only understands the regulations they challenge regulations when they do not make sense.

6. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   a. Proactive regulations are better than reactive regulations.

   b. Regulations should be worded in affirmative language rather than "do not" do this and that. This will promote better response from the industry.

7. Lessons Learned

   a. Operators do not like having many masters- Currently they follow overlapping regulations from the FAA, EPA, DOT and OSHA. This gets to be complex. Convert these to a common reference for simplification.

   b. Presentation/organization of regulations; make it easy to access, search and review. Some organizations such as Jeppesen sell tools that help. FAA should provide such tools.

   c. SOP, as a separate publication is better than to be combined with the operating manual. These two documents have different purposes and at different levels of abstraction in philosophy.

d. Quality/safety program is not mandated but is essential.

e. Plan for evolving technology (especially small/medium operators)- examples heads-down operation depending upon cockpit instruments rather than looking out, non-traditional navigation aids. Takes money to equip and train for safety.

The people involved have extremely strong personalities. They all have safety at heart. Their standards are very high. But there are issues of relationship between team members, and relationships between the team and the management that gets visibility in the audits. This is the equivalent of Cockpit Resource Management (CRM) for the organization.

Aviation 3: Cargo Operator

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

1. What regulations are difficult to follow for the industry? Which regulations do they misunderstand on a routine basis?

   It is a pretty open-ended question- difficult to answer in specifics.

2. Cultural differences between regulators and industry-Regulations say "what" is expected and industry has to know "how" they will comply. In your opinion what is the best way to see that the regulations are followed?

   We should have more maintenance technicians involved in making the regulations.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   We take the manufacturer's maintenance program and device our operator's practices. That will not change whether or not we have FAA regulations.

4. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   Reporting requirements: We have a lot of reporting requirements. It is not clear whether or not any one in the FAA looks at these reports. It is also not clear why they would want to look at this information.

   There is a need for improving the mechanics experience and training requirements. It is better to have the mechanics trained in specific types of aircraft. The training schools should be changed accordingly.

   There is room for improvement in parts usage. Currently there are parts brokers who are not regulated. They may be selling bad parts. It is the responsibility of the operator to investigate whether or not a bad part is being sold. This is difficult.

   Repair stations are not audited often enough. There is room for improvement in the consistency of service by the repair stations.

Aviation 4: FAA Repair Station

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

1. What regulations are difficult to follow for the industry? Which regulations do they misunderstand on a routine basis?

   Regulations are probably not a big issue for us because we only deal with non-flight critical equipment.

2. Cultural differences between regulators and industry-Regulations say "what" is expected and industry has to know "how" they will comply. In your opinion what is the best way to see that the regulations are followed?

   We take the regulations and add our quality control procedures to develop our own inspection procedures manual.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   For the most part we will continue doing what we are doing. We train our own mechanics. These are ex-automobile mechanics. We are in need of the same skill set.

   Record keeping is adequate. We would keep these records for warranty purposes even if the regulations did not exist.

4. Does the industry understand the intent behind the regulations or are the regulations followed blindly?

   Industry, in general, understands the intent behind the regulations.

5. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   Suspected Unapproved Parts (SUP) is not a specific problem for us. I would like to emphasize, "Know your supplier." Brokerage world is suspect since it is not regulated.

Aviation 5: Trade Association

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

1. What regulations are difficult to follow for the industry? Which regulations do they misunderstand on a routine basis?

   Part 121.273, Continuing Analysis and Surveillance System (CASS) is most often misunderstood. The regulations require that a system be in place to monitor practices with no guidance to go along. FAA has the authority to make changes to an operator's maintenance program. Operator's maintenance program is based on business decisions and should not be open for change by the FAA.

   Part 121.703 and 705 refer to service difficulties and reporting. These words are open to interpretation. Operators have difficulties in knowing what needs to be reports. A proposed AC was sent to the FAA to provide guidance in this regard,

2. Cultural differences between regulators and industry-Regulations say "what" is expected and industry has to know "how" they will comply. In your opinion what is the best way to see that the regulations are followed?

   Since words can be interpreted differently from different points of view, there is not much that can be done about this problem. However, there needs to be an arbitration system when there are differences in the interpretation of rules and regulations between the industry and the regulator or one regulator and another. Differences in interpretation can cause economic hardship to the industry.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   There are no regulations to use MSG-3 and yet the industry voluntarily follows the document because it makes sense. Industry practices such as having maintenance review board, adapting new and better ways of doing the job and adapting to changing industry is continuously being reviewed by the industry. For example, Aging Transport Systems Rule Making Advisory Committee (ATSRAC), is coming up with a number of solutions to avoid problems (such as keeping the areas around wiring clean). Most carriers want to do the right thing. The standards are written for the lowest common denominator because small operators will have an economic disadvantage to follow a lot of regulations. Usually operators do more than what the regulations specify.

4. Synopsis of current practices:

   Some operators (more often, small business operators) may not know the need for a continuous feedback system. They may have the initial maintenance schedule developed but may never change it. They may not be collecting the data that would help improve their maintenance program.

   Some operators are adapting MSG-3 like Initial maintenance schedule program with the SAE recommended Reliability Centered Maintenance (which includes the feedback system).

   Advisory material proposed by ATA to the FAA to cover CASS will be helpful. The FAA Aviation Flight Standards (AFS) has hired a contractor to develop a best practices model for CASS.

5. Does the industry understand the intent behind the regulations or are the regulations followed blindly?

   Sometimes the industry understands the regulations better than the regulators. There is a move to review the FAA classes given to flight standards inspectors to get rid of inconsistencies in interpretation or regulations. Handbooks should only illustrate best practices. They should not be written or implemented as "rule making without due process". They should not be in the form of blind checklists that are followed without being mindful of process differences that are chosen by the operator within the scope of the regulations. Proper application of regulations requires inspectors to make intelligent decisions rather than following a checklist.

6. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   Airworthiness Directives are onerous; there is a need for a process that is less onerous.

   Rules are released before any of the advisory material is written. Even the preamble is taken out when the rule is released. There is a chance that some may not understand the intent behind the rules. It would be nice to see advisory material and rules be released at the same time.

   Clarity of expression needs improvement. Lots of advisory materials are being written to clarify the regulations.

Aviation 6: Airline Maintenance Facility

1. What regulations are difficult to follow for the industry or the FAA? Which regulations do they misunderstand on a routine basis?

   The FAA does not necessarily misinterpret the 14 CFRs, but they interpret them for their own benefit or cause. They routinely pressure the carrier toward their position by disclaiming the clause "or as approved by the administrator. 14 CFRs say, "do this" or get approval of the administrator. The FAA inspectors interpret this to say that ALL activities need to be approved.

   Handbook Airworthiness Bulletins sometimes contradict 14 CFRs and Advisory Circulars. Each of these regulations was perhaps written at a different time. This can cause one inspector contradicting another.

   Risk lies with both the FAA and the industry. Time spent in satisfying unreasonable requests from the inspector can be spent in fixing a real safety problem- this is not usually understood by the FAA.

   The FAA should stop reinterpreting rules every time there is an incident/accident. The FAA takes blame for incidents and accidents and reacts with imposing more regulations on the airlines rather than fairly representing the consumers.

2. Cultural differences between regulators and industry-Regulations say what is expected and industry has to translate this with how they will comply. In your opinion what is the best way to see that the regulations are followed?

   Airlines are free to formulate their own internal procedures, and disclose only certain elements to the FAA. But if the FAA does not know all about these internal procedures, the FAA inspector may not have confidence in the airline maintenance program. However, by regulation full disclosure of the internal procedures of the company need not be revealed to the FAA.

3. What current maintenance activities will the industry do even if there were no FAA regulations?

   We would do value added items if there were no 14 CFRs. Things such as SDR's would not be done as there is currently no value added received by the carrier, FAA or industry from them. But the airline would make sure safety issues such as cracks and heavy corrosion were maintained to acceptable levels.

4. Synopsis of current practices:

   Establishing procedures such as pilot checklists, walk around inspections etc.

Proper servicing, pilot walk around for detecting ice, trailing edges of composites that are susceptible to damage, closing of all service doors,

Use of electronic devices such as TCAS and TAWS

Maintenance interval program based on ATA MSG3. Frequency of checks may go up based on the level of findings, however, the level of severity of findings is actually reduced resulting in less down time for airplanes. This is a phased check process.

Proactive quality assurance instead of reactive quality control. Want to be able to fix problems the first time- maintenance activities are followed closely to assert that the problem is indeed fixed and no new problems are introduced.

Work with the FAA with open information into company audits, findings and closure,

Use of FAA ATOS guidelines

Benchmark the suppliers

In-house heavy maintenance due to poor reliability of outside maintainers.

Establish a safety division - an independent review of maintenance activities.

5. Do the industry and the FAA understand the intent behind the regulations or are the regulations followed blindly?

Many FAA inspectors not only do not understand the intent, they do not think about the misapplication of rules. They also want blind compliance from the industry sometimes causing safety problems instead of solving any. For example 14 CFR 119 for pyrotechnic devices to be carried by aircraft crossing a body of water was a rule that made sense when there was no other technology to attract attention if the plane goes down in the water. In today's technology, it is important to audit if the intent is satisfied, rather than insisting on introducing the fire hazard of pyrotechnic devices in the cockpit.

FAA should get away from a black and white interpretation of rules, and should consider safety in the actual implementation. An example is an instance where a single rivet was not flush with the skin of the airplane. Since this is not documented in the maintenance manual, extensive substantiation of data was required by the inspector.

There are FAA inspectors who believe in zero risk, and look at all problems at the same level of importance. This imposes undue burden on the industry to address non-safety specific problems at the same level of priority as the safety critical problems.

There are FAA inspectors who can work with the industry and solve problems based upon their safety risk. This should be the model to strive for.

6. What would you like to see changed in the rules, methods of audits and inspections, authority, experience requirements, reporting requirements, parts usage etc?

   Reporting requirements (SDR) imposed by the FAA has many problems. Reporting is onerous, not helpful to either the industry or the FAA, and no one is looking at these reports. It is not clear why the FAA needs it or what is FAA going to do with it. Further, this information is public data and there may be instances where the data is taken out of context by press for sensational reporting.

7. Lessons Learned

   Total reevaluation of 14 CFRs is needed to check the original intent and compare it to what is being required in today's technology

   Evaluate what an airline is doing at the system level. Basics such as pilot checklists, walk around the airplane, closing all service doors etc are very important.

   Eliminate uneven interpretation of rules for reason other than technical or safety reasons. The way 14 CFRs are written and the way 14 CFRs are interpreted by the inspectors can result in an uneven field. Competitive edge can come from the administrator.

   Appeals process needs to be examined - this process does not work because of fear of retribution.

   Airframe and Powerplant (A&P) training requirements need to be examined. School curricula are out of date; not keeping up with technology. Airlines have to train these new graduates to learn specifics on latest technology such as composites.

8. Other Comments:

   Would like to see passengers appreciate the sensitivity of instruments in an aircraft - for example spilled Coca Cola in the cabin is highly corrosive.

NASA 1: Shuttle Systems Engineering

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

General Notes:

- Shuttle has. 98 system reliability, change out to 100 parts helps get to 1 in 250
- Not enough history to trust systems
- Launches too infrequent to sample, i.e. tanks
  - Licensing is higher cost due to not enough repeatability or reliability – certification cheaper
  - Technology maturity isn't there – wear them down testing the parts
- Nose gear door flaps open due to flimsiness
- Good decomposition and coordination of subsystem but NASA doesn't integrate them well
  - Stovepipe manufacturing – tremendous duplication
  - SLI RLV still decomposition and stove piping – already going down wrong path
  - Decomposition and stove piping provide a short term budgetary control
  - Stove piping is political
- Unclear delineation of roles and responsibilities in NASA
- FAA should be working with NASA on criteria for what to test…. testing engines…etc.
- If technician has to do something to fix in between it's uncertifiable
- Demonstrate that critical failure not caused by a certain event
- Can't use Minimum Equipment List (MEL) because parts don't have reliability
  - Race to bottom to get to the worst part rather then the working on just "two" parts
- Integrates cell is bottleneck – 45 days, now 6-8 launches, 11 launches needed
- Pads are often down for O&M for months
- Hardware is unforgiving?
- Quantitative risk assessment 1/250
- Safety factor on shuttle ~ 1.4, aircraft ~ 2+
- Mass fraction and propulsion are the two key RLV drivers
- Checks so many because they know what the value is
- Licensing means low confidence and reliability and is high costs
- Certification shows confidence in system
- Decomposition management and coordination
- Reduces risk in short term and budgetary reductions
- Get paper concept of OPS for lessons learned has also functional breakdown
- FAA should publish testing requirement

Answers to Questions:

1. What STS technologies that you use are common to aircraft industry?

   Many flight subsystems (airframe / structure, landing gear, turbine power units, avionics, hydraulics, etc) are all-common or share a pedigree or counterpart to common aircraft industry systems. The significant difference often lies in the sensitivity to weight, it's effect on the resulting margin in a design, the operability and reliability of the system / technology and the general technology maturity of the specific application.

   Ground systems use readily available parts for pneumatics, cryogenics, electronics etc (valves, cabling, control systems, etc). A significant difference lies in the extent and complexity of facility and equipment maintenance centered on a low volume operation (a handful of launches are the end product, per year) as compared to private sector and higher volume operations (e.g. manufacturing environments where facility and equipment operations tempo supports readiness and speed for producing products on large scale).

2. What equipment/technology is unique to the STS? What are operations are unique to the STS?

   Very unique RLV technology typically includes:

   Propulsion / main engines, orbital maneuvering engines, thrusters

   Power / fuel cells and turbine power units

   Thermal protection systems materials and processes

   Cryogenics systems (valves, seals, sensing, umbilicals, facility and equipment)

   Future-IVHM ground and flight systems, active in-flight and/or in-line for processing

3. Which of your STS operations and maintenance (O&M) procedures are common with the aircraft industry and commercial RLV concepts?

   Few to none, except at a high functional level. Totally different in scope and root cause related to industry / technology maturity.

4. Which parts of your O&M activities are peculiar to the STS only?

   Almost all.

5. Have you considered the need to change your maintenance activities to keep up with the evolving technology? How do you address them?

Yes. “Design for support” vs. “support the design” requires major flight system maturity increases. Ground systems investments require higher flight rate and/or synergy (enabled) with flight system advances.

6. Do you have certain triggers that will prompt you to take a second look at your current procedures?

Yes, recurrence control (reactive systems), and some pro-active efforts (Shuttle upgrades).

7. What activities do you consider most important to assure safety of:

   a. Your Crew

   b. Mission Specialist

   c. Public on the ground

   d. Flying public on other aircraft/RLV

Proper process control (near term fix) coupled with better overall inherent reliability (far term).

8. What level of experience, knowledge and skills do you expect in your mechanics?

High – typical technician should have a few to 5 years experience before performing almost any operations alone without a more experienced lead.

9. What is your initial training program, noting that you are unlikely to find "experienced STS mechanics"?

As per above, shop controls, extensive training and grouping of more experienced techs with less experienced techs. Certification processes and tracking.

10. How do you plan to keep up with training as technology evolves?

Integrate into more automated work control systems (logistics, maintenance and monitoring, work generation, scheduling and point of execution verification and automated IT systems.

11. What is your training pipeline for crew/mission specialists and maintenance technicians?

n/a to my background.

12. What type of repair facilities or procedures do you think could carry over to commercial RLV maintenance operations?

Commercial RLVs of similar technology and reliability will likely require many of the same repair facilities and operations. Only 2nd order effects may improve as one generation of technology on ground systems becomes implemented by another, But, without flight systems maturity being improved the rest of the functional work content may remain the same or even worsen, depending on the concept.

13. What processes or improvements were instituted to provide a quicker reconstitution of the STS for it's next launch?

May be or have been?

May be:

TPS – use the newer materials….aluminum enhanced thermal barrier (AETB-TUFI-8) vs. the old tile

Put in Electric Actuators in select low horse-power systems (nose gear?) and eliminate the hydraulics…explore other phasing options

Put in a higher horsepower pump for ground hydraulics to be able to use an on-flight system…

Automate and sub out all work control (generation, scheduling, execution)

Automate point of execution work verification.

14. What type of records do you keep to help you in assessing/assuring safety of repairs as well as to investigate any future incidents?

Systems at KSC include PRACA, OMIs, OMRSD tracking, etc.

Not my area.

15. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

Spec's and vendors exist. NSLD processes in place for this.

Not my area.

16. What are your criteria for safety in repair?

Specific to operation. (Very broad question)

17. How do you determine that the STS is properly serviced and can be returned to service?

Specific to operation. (Very broad question)

18. How did you determine the periodicity of preventive maintenance?

KSC standards.

Specific to operation. (Very broad question)

19. How did you determine the minimum list of equipment that must operate correctly for safety of flight?

This concept of MEL NOT used in STS.

20. How do you assure safety of flight?

Specific to operation. (Very broad question)

21. How do you determine that repairs are needed? What kinds of inspections do you envision to find problems as the STS matures?

Specific to operation. (Very broad question)

22. What portions of the STS are inspected before every flight? After every flight?

ALL critical parts (fail modes 1, 2). What parts are NOT inspected flight to flight may be less scope to answer.

23. What procedures, if any, do your routine STS operations use to work seamlessly with the ATC operations?

Unknown. Not my area.

24. What elements of analysis did you use from design to help you with frequency of inspections, repairs and replacements?

KSC typically responds to analysis for flight systems and then reacts to respond and execute a requirement. In many cases, KSC personnel actively participate in analysis by providing test data, executing test and checkout, etc. Ultimately analysis is translated into requirements and then into work plans and execution. Analysis typically requires more margin in decision making than having data points or actual data.

25. What types of analyses would you recommend if your repair or alteration changed the original design?

Varies – too broad a question.

Example – engineering may require an analysis of a sealing surface based on deciding to leave a defect on it that has certain depth. Or engineering may want an analysis done by lab of certain residue in a LOX clean line to determine if the residue needs added attention or removal that may not be easily accomplished. Or engineering may request that vibrations for a ground pump be analyzed for any trending such as if indicating a bearing problem or such that could lead to failure.

Most all of these processes and contingencies are well defined by experience and/or procedures/requirements in place.

26. Do you use parts manufactured in foreign nations?

n/a

27. What types of security precautions do you take in hiring your mechanics and checking integrity of third party vendors?

Unknown. Not my area.

28. Do you use any parts manufactured for the aircraft industry?

See question 1 reply.

29. Do you use parts manufactured for the automobile industry?

Wish we did (unlikely).

30. How do you measure the quality of a part as "usable"?

Unknown…re NSLD and STS cert processes.

31. How do you prevent some one from using a rejected part?

See Q30. (parts are tagged, stamped, and returned I believe, bar coding and S/N tracking).

32. How do you plan to keep communication links between various people in your team namely a crew member who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem.

At KSC…try paperwork.

33. What procedures do you use (that are not in the 14 CFRs) in order to streamline your work and adding to safety?

n/a

NASA 2: Shuttle Processing Modeling

The key facts emerging from this interview include:

- The Shuttle processing flow is broken into phases of flight with 26 processes involved throughout the processing flow.
- Although built for Shuttle, ShuttleSim was modified for a Generic RLV. It is a flexible and modifiable tool, Figure 2, Generic RLV Flow.
- Inputs to validate the model came from numerous data sources from NASA KSC.

NASA 3: Contractor

- Vision Spaceport is an operations tool.
  - The Lockheed Martin Denver office uses it for a costing tool.
  - Space and aviation data were used to develop and validate the tool
  - The X-15 cycle time prediction was 8 days while in reality it was once per week over the 199 flights.
  - Mercury Redstone was within 3% of prediction for turn-time.
- GSE and facilities at KSC are defined by acquisition method.
  - i.e. The Mobile Launcher is considered a facility.
- ASTWG adopted VSP.
  - The ASTWG broke out humans from payloads
- KSC uses PRACA (Problem Reporting and Corrective Action) database for all problem reporting.
- Shuttle was built before there was a mission (Space Station) for it.
  - STS is the transport for Station.
  - There was a conscious decision to build it first.
  - Development of STS didn't focus on requirements (it should have been a people carrier since the Saturn and other launchers had the lift capability).
- There is a need for a Ground System Technology development for turn-around improvement.
  - The last development was in '50s with the Atlas ICBM refueling requirement to fuel as it rises out of silo.
  - There are no new rapid fueling requirements.
  - Atlas V uses new approach for safety and fewer moving parts.
    - Uses pressure not pumps
    - Reduces parts count

RLV 1: RLV Developer

Contents of the dialogue have been re-organized into the following paragraphs and are not necessarily in the chronological order of discussed topics.

- Market is tourism, need core market as a sustainer
- Launch costs have to be really, really low
- Need core market to keep in black
- $900 for one sortie (fuel, oxidizer, pressurant, touch labor & mission planning)

  Learn from 14 CFRs by looking at reasons there:
    - Have to carry an aircraft structure as a factor of safety derived from aluminum primary structure composite structure safety up for debate
    - Should FAA determine factor of Safety? Not right now but one day
    - 14 CFR has detail on flying qualities should aircraft have?
    - Should RLV be subset?
    - RLV has big changes in moments of acceleration – flying qualities need to be reasonable through out phases but shouldn't demand load structures through phases
    - Any vehicle design will have established criteria for success then use that as empirically for regulation and sharing
    - Feels sufficient to use A&P to do maintenance maybe one day a rocket rating but no training now
    - FAA/AST wants to help
    - More sophisticated white papers
    - No NPRM until someone is flying
    - May have to start over when flying starts
    - Must allow 1st entrants to do what they've done successfully
    - FAA may not be able to avoid approval/regulation process due to liability issues
    - Common carrier as threshold for FAA regulations
    - RLV as "job" or worse RLV when it never occurs it's dangerous the way risky territory
    - FAA will never let RLVs fly passengers without life support suits, etc. Any passengers will require training.
    - No demonstration yet (1st generation – suborbital, regular –years down the road) so will be done just to do it.
    - Visit to see ops 1st hand
- Is Space Access list of 21 Gap Areas a good start?
    - Thermal Protection System is important and not covered
    - No remote operations
    - Cryogens regulated by OSHA – keep FAA out of it
    - Venting inter spaces of structure, important but not cryogenic venting
    - Outgassing – no payloads that vacuum sensitive
    - Solar heating – not unique

    - Atomic oxygen – not unique
    - Microgravity – not concerned as posing risks to crew (acrobatic pilots not regulated for Gs)
    - Deorbit – yes & more so with orbital degree management (can't do EIS because we don't own space) (current mass of objects being orbited by RLV not hardened)
    - Re-entry need highly operable thermal protection system
    - Fuel reserves – accelerator or boost glides usually burn to fuel exhaustion but carries a small reserve
    - May be an issue but can't envision how to cover there with all possible versions
    - Engine inoperative capability
    - Noise take off and sonic boom NO
- Hates software, he's a hardware guy
    - Only test flight fatality of F-15 was a S/W failure on flight control augmentation-stability augmentation and neutral guidance
    - Software can/will fail & too hard to plan for from regulatory position
    - Redundant systems for reentry positioning
    - Daylight/VFR only aircraft experimental aircraft done in R&D category but now R&D & exhibition at their convenience
    - Now operating as VFR daylight only
    - Bulk of test flight above 60,000 feet
    - Propellant reserve in case of batched re-entry to override glide
    - Staging – next generation will have stage capacity when not carrying passengers, micro satellites, government market – secret (not disclosable)
    - Has data collection but not automated.

RLV 2: RLV Developer (X-34)

- NASA terminated the X-33 and contractor, the X-34, on the same day on 1 Mar 01
- Stopped doing system engineering and went to analysis only
- SLI – 3 contractors doing systems level architecture assessment
    - Boeing
    - Lockheed
    - Orbital/Northrup Grumman
- All same system engineering studies on 3 different designs
- worked 15 years with NASA
- Two of the SLI procurements so far have been very "wide open"
- NASA interested in studying crew systems but let the contractor bid based on generalities and not specifics
- NASA letting the industry bring creativity into the process of design development rather than providing line by line direction
- In February of next year there will be an RFP (request for proposals) out of systems requirement review
- 3 Primes have been left up to their own devices on how to meet requirements
- NASA has gone out of the way to let industry lead
- SRD document is on it's 8th generation so far
- X-34 was an operations demonstrator not only in technology but O&M as well
- There were 25 flights scheduled and goal was get turn-time down to 2 weeks or less
- Goal at one time was to have only 12 people turning it around then it went to 10 people at the field site which included the support staff like secretaries
- Never flew
- Did use 10 folks during tow testing on lake bed but when it came to crew size to turn they were augmented by a large number of NASA personnel and the contractor team of engineers
- perspective was the X-34 was just a demonstrator and not ever intended to fly operationally
- It has a capacity to fly 400 lbs of embedded experiments but never deliver a payload to space
- There were no payload doors and there was 400 lbs capacity in each of the wing strakes

Q: How did O&M underpin the design?

- & M never underpinned the design aspect – composite vehicle but could easily remove and replace for some turn around requirements
- Space flight qualified avionics Personnel - military jet background
- Ran all profiles through FAA and required coordination

- Early flights at White Sands with plans to transition later to Edwards during higher mach flights
- For the L1011 “package” (the L1011 carrying (on the underside) the X-34 without it's full components) it was the X-ticket for flying around the Continental United States (CONUS) [FYI, the X-34 was carried on the underside of the L-1011]
- Had to have L1011/X-34 package certified
- Flew 2/3 of the scheduled captive carrier flights without working engine or fluids in the X-34
- Called certification flights as opposed to being licensed
- Very painful process and the certification of the “package” was never resolved
- Real fundamental issue is certification of the whole space process
- Work was being done with FAA on modifying 14 CFR 127.1

- ***Q: Was it demonstrated to show ease of maintenance?***
  - Most of the critical remove and replace parts were accessible
  - Toughest part was to unbolt a panel and remove it which wasn't tough
  - Any one developing an RLV today: IVHM
- ***Q: What impact does O&M/design features have on public safety?***
  - Companies don't want to incur liability so like all plan accordingly
- ***Q: Did you run Ec models?***
  - Yes with their flight assurance manager with the 30 x 10-6 formula just like ELVs, Cape and Vandenberg. 14 CFR 127.1 involved.
  - Space industry is going to great lengths to disprove public perception of the danger associated with space
  - Space industry will NEVER get to aircraft like operations
  - 2 Technologies unique to flying to space:
    - Energy to get into space; i.e., propulsion systems

    Negating that energy to come back from space; i.e., thermal protection systems
- ***Q: Can it be done without government funding?***
  - The costs are prohibitive without gov't assets
  - For thermal protection needs tiles and blankets to protect on reentry
  - There is breakthrough technology that might help called SHARP (structural and thermal protection) but it will be 5 years from now before implementation
- ***Q: What will drive the development of technology with military need, Sputnik or other events to act as catalyst?***
  - There is no incentive for the commercial industry to develop technology themselves
  - It's different than 10 years ago when industry was racing to maintain satellites
  - NASA is just doing a shotgun approach but needs to focus on the 2 technologies above
  - And a 3rd technology: materials

    - Concur
    - Military will be the driver
- ***Q: We would like to send you our working superfunctions listing and see if you could add too or comment on it.***
    - No problem
    - Back to tech. Dev't: By the FAA involving themselves and RTI at this stage in the game then it's looks more to the public like space is becoming "normalized" which is a significant shift in itself
- ***Q: What are your thoughts on what the X-prize push will do for space?***
    - Touched a nerve! It is wrong to send people to the International Space Station as it's an experiment platform and international effort and NOT public property
    - Maybe U.S. can put together a "tourist condo" in space

<u>RLV 3: Interview: Developer</u>

9. What RLV technologies that you use are common to aircraft industry?

We are looking at using aircraft engines on the booster for flying it back to its launch facility. The software that will control the vehicle during horizontal flight and landing will most likely use aircraft algorithms and modules. Landing gear and wing designs will be patterned after aircraft designs.

10. What equipment/technology is unique to RLVs?

Our launch is planned to be vertical and use rocket engines. Also the booster and orbiter are planned to return to their launch facility autonomously.

11. Which of your RLV operations and maintenance (O&M) procedures are common with the aircraft industry?

The only ones presently are for the jet engine. The vehicle health monitoring approach will rely heavily on aircraft system design for its architecture and algorithms.

12. Which parts of your O&M activities are peculiar to RLVs only?

Our operations will be drawn from ELV and Shuttle backgrounds but updated to require less hands on activity and quicker turnaround.

13. Have you considered the need to change your maintenance activities to keep up with the evolving technology?

Our maintenance activities have always kept up with evolving technology as it is applied to the launch vehicles. We will continue to follow the same pattern in the future.

How do you address them?

When new technologies are proposed for our launch vehicles we thoroughly investigate the impacts they will make to the vehicle, facilities and operations before they are incorporated.

14. Do you have certain triggers that will prompt you to take a second look at your current procedures?

We review our operations and procedures and update them as we find better ways of performing the operations.

15. List the activities that your company will do even if the FAA does not impose them - in the current remote area operations and in the future populated area operations (if you are planning on future launches from or over flights of populated sites)

We plan to identify and control hazards in our designs as we develop our vehicles and operations.

16. What activities do you consider most important to assure safety of:

    a. Your pilot

    Presently the only pilots will be NASA trained and certified. The safety of the pilots and crew are the number one requirement of the human rated RLV systems.

    b. Passengers

    Presently the only passengers will be NASA crew members. The safety of the pilots and crew are the number one requirement of the human rated RLV systems.

    c. Public on the ground

    Public safety is of great importance to our RLV program and Launch vehicle autonomous flight operations in the National Airspace will need FAA approval. We need to know as soon as possible what process FAA is going to follow to license RLVs. This will allow us to design our vehicle to best protect the public.

    d. Flying public on other aircraft/RLV

    The use of these vehicles in the National Airspace is something that the FAA and the RLV contractors need to address soon. Most of the RLV concepts do not have air breathing engines for operation in the atmosphere so the flight control of launching and returning vehicles will need to have airspace cleared for them much like the shuttle does today.

17. What level of experience, knowledge and skills would you expect in your mechanics?

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using. Technicians used by the launch vehicle industry have to be certified for their job assignments. In the past, they have tended to have many years of experience before having to perform critical tasks. Those job assignments are well defined and operate to approved procedures.

18. What would be your initial training program, noting that you unlikely to find "experienced RLV mechanics"?

We do expect to find “experienced RLV mechanics” since the RLV will be a combination of the best of ELV and Shuttle programs updated to require less maintenance and be easer to turnaround for the next launch.

19. How do you plan to keep up with training as technology evolves?

We deal with this today for our ELV and Shuttle operations and we plan to use those techniques and update them for the new technologies we will be using.

20. What would you expect in a school that trains these mechanics?

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using.

21. What type of repair facilities do you expect for a quick turn around of the RLV?

Presently we plan only minor repair and these we will perform at the launch site unless the subsystem / part needs manufacture level repair.

22. What type of safety processes do you expect in your repair facilities?

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using. Operations and maintenance procedures are approved in advance by qualified engineers and specify the qualifications required of the technicians. No operations or maintenance activity is performed on the vehicle without an approved procedure.

23. What inspection do you impose on

    a. The mechanics

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using.

b. Third party vendors

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using.

24. What type of records do you keep to help you in assessing/assuring safety of repairs as well as to investigate any future incidents?

Our record systems will probably be mostly computer based and easily accessible for mechanics performing repairs as well as incident investigations. Repairs will be accomplished via approved procedures that are archived in the event of any future anomalies.

25. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

We plan to use a streamlined version of what are used today in the ELV and shuttle. Only parts certified to be acceptable may be used per the procedures. Quality control verifies that any parts that require rework or repair are processed and verified by procedure to be equivalent to new parts.

26. What are your criteria for safety in repair?

We plan to use a streamlined version of what are used today in the ELV and shuttle. Repairs will be accomplished via approved procedures. Only parts certified to be acceptable may be used per the procedures. Critical repairs have safeguards to ensure a single human error cannot degrade a safety feature.

27. How do you determine that an RLV is properly serviced and can be returned to service?

We plan to use a streamlined version of what are used today in the ELV and shuttle. Certified technicians, operating to an approved procedure, and with adequate oversight, verify and certify the vehicle is ready for flight.

28. How do you determine the periodicity of preventive maintenance?

We plan to use a streamlined version of what are used today in the ELV and shuttle.

29. How do you determine the minimum list of equipment that must operate correctly for safety of flight?

We plan to use a streamlined version of what are used today in the ELV and shuttle. Critical equipment and functions are identified via hazard analysis. That analysis inputs checks into the procedures to ensure equipment is verified ready for flight.

30. How do you assure safety of flight?

We will identify and control hazards in our designs before our system flies to assure the safety of flight.

31. How do you determine that repairs are needed?

The technology will drive the repairs and when they are needed. Depending on the level of criticality, and its history, equipment will be repaired or replaced on either an as-needed basis between flights or a periodic basis. What kinds of inspections do you envision to find problems as the industry matures? This will be determined by the operations concept. Early in the program, a lot of manual inspections will be utilized to verify critical functions. As the program develops experience, the health management system will be certified to monitor many critical functions. The aircraft industry will be a model for how this split between manual and automated inspection will be done.

32. What portions of the spacecraft would you inspect before every flight?

After every flight? These well be determined by the technologies incorporated on the RLV and the operations concept. All critical functions will be verified to be operating properly prior to each flight.

33. What procedures do you envision your routine RLV operation to work seamlessly with the ATC operations?

The interaction of a commercial RLV in the National Airspace with the ATC operations is yet to be determined. We would hope that it could be incorporated in a seamless way.

34. What elements of analysis do you use from design to help you with frequency of inspections, repairs and replacements?

The analyses needed will be determined by the technologies we use in the RLV and its ground support systems. An FMECA and a hazard analysis, in addition to hardware certification test data, provide the basis for hardware criticality and inspection, repair and replacement frequency.

35. What types of analyses do you recommend if your repair or alteration changed the original design?

We will identify and control hazards in our designs and mitigate them before the system is incorporated. All repairs or alterations will be tested for proper functionality. All critical or redundant functions will be verified.

36. Do you plan to use parts manufactured in foreign nations?

These type of decisions have not been made yet.

37. What types of security precautions do you take in hiring your mechanics and checking integrity of third party vendors?

Our mechanics will have to undergo security checks much like they do today for the ELV systems. Third party vendors have not been addressed at this time.

38. Do you plan to use parts manufactured for the aircraft industry?

There will be some but the extent has not been determined yet.

39. Do you plan to use parts manufactured for the automobile industry?

We do not see much application for automobile parts in our vehicles.

40. How do you measure the quality of a part as "usable"?

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using.

41. How do you prevent some one from using a rejected part?

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using. Procedures will require verification of hardware certification.

42. How do you plan to keep communication links between various people in your team namely a pilot who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem.

We plan to use the techniques developed for the ELV and Shuttle and update them for the new technologies we will be using..

RLV 4 Interview: DC-X

- DCX – not sure a functional breakdown but focus from day one was if there was not a high level of reliability then the program was not doable
- Too many unknowns because nobody understood this stuff
- Some operability and high-level objectives accomplished
- Some reports might be available from contractor out of Kirtland AFB
- Boeing Airplane Company tried to lay out process “when build commercial aircraft you know reliability of individual parts” – some in standards and some in historical process

- Before flying first time you have database to give idea of what reliability will be

RLV 5 Interview: Developer

1. What RLV technologies that you use are common to aircraft industry? steering, automatic pilot, quality control etc. all of them basically. our vehicle is simply an airplane with a rocket engine and capable of dealing with zero atmosphere (space) with small rocket engines for maneuvering.

2. What equipment/technology is unique to RLVs? rocket motors

3. Which of your RLV operations and maintenance (O&M) procedures are common with the aircraft industry? basically all.

4. Which parts of your O&M activities are peculiar to RLVs only? vertical ocean launch. ours is the only ocean launch that i'm aware of.

5. Have you considered the need to change your maintenance activities to keep up with the evolving technology? How do you address them? no

6. Do you have certain triggers that will prompt you to take a second look at your current procedures? no

7. List the activities that your company will do even if the FAA does not impose them - in the current remote area operations and in the future populated area operations (if you are planning on future launches from or over flights of populated sites) we launch from the ocean 14 cfr enough away to keep insurance costs down

End of inputs for the RLV questions, the rest were in common to the STS and RLV questions.

STS Interview Questions

1. What STS technologies that you use are common to aircraft industry?
Many flight subsystems (airframe / structure, landing gear, turbine power units, avionics, hydraulics, etc} are all common or share a pedigree or counterpart to common aircraft industry systems. The significant difference often lies in the sensitivity to weight, it's effect on the resulting margin in a design, the operability and reliability of the system / technology and the general technology maturity of the specific application. Ground systems use readily available parts for pneumatics, cryogenics, electronics etc (valves, cabling, control systems, etc}. A significant difference lies in the extent and complexity of facility and equipment maintenance centered on a low volume operation (a handful of launches are the end product, per year} as compared to private sector and higher volume operations (e.g. manufacturing environments where facility and equipment operations tempo supports readiness and speed for producing products on large scale}.

2. What equipment/technology is unique to the STS? What are operations are unique to the STS?

- Very unique RLV technology typically includes:
- Propulsion / main engines, orbital maneuvering engines, thrusters
- Power / fuel cells and turbine power units
- Thermal protection systems materials and processes
- Cryogenics systems (valves, seals, sensing, umbilicals, facility and equipment}
- Future-IVHM ground and flight systems, active in-flight and/or in-line for
- processing

3. Which of your STS operations and maintenance (O&M} procedures are common with the aircraft industry and commercial RLV concepts?
   Few to none, except at a high functional level. Totally different in scope and root cause related to industry / technology maturity.
4. Which parts of your O&M activities are peculiar to the STS only?
   Almost all.
5. Have you considered the need to change your maintenance activities to keep up with the evolving technology? How do you address them?
   Yes. "design for support" vs. "support the design" requires major flight system maturity increases. Ground systems investments require higher flight rate and/or synergy (enabled) with flight system advances.
6. Do you have certain triggers that will prompt you to take a second look at your current procedures?
   Yes, recurrence control (reactive systems), and some pro-active efforts (Shuttle upgrades).
7. What activities do you consider most important to assure safety of:
   a. Your Crew
   b. Mission Specialist
   c. Public on the ground
   d. Flying public on other aircraft/ RLV
   Proper process control (near term fix) coupled with better overall inherent reliability (far term).
8. What level of experience, knowledge and skills do you expect in your mechanics?
   High -typical technician should have a few to 5 years experience before performing almost any operations alone without a more experienced lead.
9. What is your initial training program, noting that you are unlikely to find "experienced STS mechanics"?
   As per above, shop controls, extensive training and grouping of more experienced techs with less experienced techs. Certification processes and tracking.
10. How do you plan to keep up with training as technology evolves?
   Integrate into more automated work control systems (logistics, maintenance and monitoring, work generation, scheduling and point of execution verification and automated IT systems.
11. What is your training pipeline for crew/mission specialists and maintenance technicians?
   n/a to my background.
12. What type of repair facilities or procedures do you think could carry over to

commercial RLV maintenance operations?

Commercial RLVs of similar technology and reliability will likely require many of the same repair facilities and operations. Only 2nd order effects may improve as one generation of technology on ground systems becomes implemented by another, But, without flight systems maturity being improved the rest of the functional work content may remain the same or even worsen, depending on the concept.

13. What kind of processes or improvements were instituted to provide a quicker reconstitution of the STS for it's next launch?

    May be or have been? May be: TPS -use the newer materials (AETB- TUFI-8) vs. the old tile put in electric actuators in select low horse-power systems (nose gear?) and eliminate the hydraulics. Explore other phasing options: Put in a higher horsepower pump for ground hydraulics to be able to use an on-flight system, automate and sub-out all work control (generation, scheduling, execution), or automate point of execution work verification.

14. What type of records do you keep to help you in assessing/assuring safety of repairs as well as to investigate any future incidents?

    Systems at KSC include PRACA, OMI's, OMRSD tracking, etc.

    Not my area.

15. What are your criteria for buying and using replacement parts with assurance in the quality, safety and reliability of these parts?

    Spec's and vendors exist. NSLD processes in place for this. Not my area.

16. What are your criteria for safety in repair?

    Specific to operation. (Very broad question)

17. How do you determine that the STS is properly serviced and can be returned to service?

    Specific to operation. (Very broad question)

18. How did you determine the periodicity of preventive maintenance?

    KSC standards. Specific to operation. (Very broad question)

19. How did you determine the minimum list of equipment that must operate correctly for safety of flight?

    This concept of MEL NOT used in STS.

20. How do you assure safety of flight?

    Specific to operation. (Very broad question)

21. How do you determine that repairs are needed? What kinds of inspections do you envision to find problems as the STS matures?

    Specific to operation. (Very broad question)

22. What portions of the STS are inspected before every flight? After every flight?

    ALL critical parts (fail modes 1, 2). What parts are NOT inspected flight to flight may be less scope to answer.

23. What procedures, if any, does your routine STS operation use to work seamlessly with the ATC operations?

    Unknown. Not my area.

24. What elements of analysis did you use from design to help you with frequency of inspections, repairs and replacements?

    KSC typically responds to analysis for flight systems and then reacts to respond and execute a requirement. In many cases KSC personnel actively participate in analysis by providing test data, executing test and checkout, etc. Ultimately analysis is translated into requirements and then into work plans and execution. Analysis typically requires more margin in decision making than having data points or actual data.

25. What types of analyses would you recommend if your repair or alteration changed the original design?
    Varies -too broad a question. Example -engineering may require an analysis of a sealing surface based on deciding to leave a defect on it that has certain depth. Or engineering may want an analysis done by lab of certain residue in a LOX clean line to determine if the residue needs added attention or removal that may not be easily accomplished. Or engineering may request that vibrations for a ground pump be analyzed for any trending such as if indicating a bearing problem or such that could lead to failure. Most all of these processes and contingencies are well defined by experience and/or procedures/requirements in place.
26. Do you use parts manufactured in foreign nations?
    n/a
27. What types of security precautions do you take in hiring your mechanics and, checking integrity of third party vendors?
    Unknown. Not my area.
28. Do you use any parts manufactured for the aircraft industry?
    See question 1 reply.
29. Do you use parts manufactured for the automobile industry?
    Wish we did (unlikely).
30. How do you measure the quality of a part as "usable"?
    Unknown...re NSLD and STS cert processes.
31. How do you prevent some one from using a rejected part?
    See Q30. (parts are tagged, stamped, and returned I believe, bar coding and SIN tracking).
32. How do you plan to keep communication links between various people in your team namely a crew member who may have suspected a problem, a mechanic who may have diagnosed the problem, another mechanic in a different shift trying to work the problem, yet another mechanic in another shift trying to finish the problem. At KSC...try paperwork.
33. What procedures do you use (that are not in the 14 CFRs) in order to streamline your work and adding to safety?

RLV 6 Interview: Industry

- X-33 Interview with LMCO
- Interviewee worked Flight Assurance, then Fight Operations, then Deputy Program Manager, then Program Director.
- Flight Assurance assured that they could safely and successfully accomplish objective of flight and return. He was also main external interface with outside agency for the purposes of obtaining flight approval from the various stakeholders.
- There was a joint industry/NASA “X” vehicle and a much larger venture called Venture Star

- Since FAA doesn't regulate other gov't agencies' vehicles they simply were interested in traffic avoidance (for the X vehicle)
  - They did interface with AST a lot for the RLV portion of the project and also kept AST involved in the X-33 for their educational benefit
- X vehicle was about 85 % assembled and 95% of parts delivered when program was shut down
- RLV – completed preliminary design and closed the design (concept was sufficiently mature so they could launch a detailed design)
  - The purpose of the X vehicle was to prove out technology (the concept) and provide experimental verification – determination of some of the parameters and O&M
- Some of parameters like aeroheating (density, how it wrinkles in flight) carried wide dispersions and could be 'off' by as much as 50%. Must be verified through flight testing.
- Designed to take a "tippy toe" step in that realm but ended up being a major step as the X vehicle was a more severe environment in addition to providing an operations verification…to drive down and lower costs
- More sever Aeroheating on small vehicle vs. design for V. Star had to do with heat rate
- How robust? Concerned heat rate and heat load
  - Heat load is larger but heat rate is the defining parameter in the vehicle – determines bending and stress on panels
  - Rate more severe on the X vehicle.
  - The tighter the radius the higher the stress so the RLV having the larger radius would endure a much less severe an environment
  - Catalytic heating was experienced but didn't know magnitude until it was flown. No vehicles to date have needed to worry about catalytic heating (ceramic tiles are inert.)
- The engine nozzle/propulsion system was unique. A one of a kind – never been flown before and had many, many ground hours of testing.
  - The aerospike engine competed for Shuttle propulsion but lost to SSME
  - No one had ever flown it – Major objective
- 3rd Major Objective was the O&M for the vehicle
  - As part of objectives given turn around times as one of the key cost drivers was turning it around for the next mission – object was to meet turn time for normal vehicles
  - Designed around that so could inspect, load and turn for next flight within certain parameters (time criteria)
  - To get turn time down – a couple things done – designed thermal protection system that was robust (unlike tiles on shuttle) so quick inspection and repair (panel off in 6 mins and another on in 6 mins) – 1200 panels on the vehicle
  - Another thing for quicker turn was it was a single stage vehicle so didn't have to put pieces together – just checked subsystems like airplanes – you didn't have to rebuild it

- So idea was if you inspect it and had criteria for acceptability. We were intended to inspect the X vehicle manually. The RLV would have an automated inspection possibly using laser or other optical techniques.
- Shuttle can't fly through cloud and subsonic or transport speed as all thermal protection would be sandblasted
  - They had metallic system so could even take a bird strike
- To extrapolate X-33 to Venture Star did preliminary plan have O&M type actions like an MEL or min equipment list
  - For shuttle it's 100% of everything (laughter). Initially, RLVs would also require 100% (I suspect.) Eventually, as we all gain confidence, we might find some acceptable exceptions to this practice.
  - On STS – original design computers – one always in a back up mode so it was designed and algorithms are completely different then other 4 and doesn't talk to others
    - Original idea was you could fly on 3 but on Shuttle no one will EVER do that
  - Brings to mind cost/benefit
  - No one in near future will ever fly a space vehicle will ever flight with a part of the avionics system not working
- Might get away with launching a system with some sort of payload interface that is dual redundant – may be tempted to fly that but not anything that is single redundancy
- Can't build it in because of the margins
- Simple Example: On an airplane you lose all your radios but you don't die – on a space vehicle there is a good possibility you would die
- The margins are not let there to allow robust flexibility you can expect in aviation
- Fairly robust margins on the x vehicle
- Our RLV was designed so the you could lose an engine on the pad and still fly the mission safely - may not accomplish mission but could fly to completion and land
  - Important characteristic of a launch vehicle which is going to fly over people
  - He told AST a lot is that all launch vehicles fly over people and there is always a chance we are going to drop an STS into Paris someday – low probability but not zero
- It's a cultural thing that we don't want a space vehicle flying over our head even if as safe as aircraft
  - We're conditioned to expect over water launches and that was needed as parts fell away (and things blew up on the pad) but eventually we don't want to be constrained to launching just over the water
  - Wright brothers out of Ohio started out on beach too but we now have inland airports.
  - How do we do this with Rockets? At this point in the game – today – there is a learning curve to do and convincing of authorities that we have act together enough to fly over people
  - My recommendation/compromise: So do flight test over range and once proven let us fly over people – give license

- However, is 10 flights into flight program and safe then could we go inland and meet a different criteria with Ec or like criteria
- Could establish that far into burn you could fly over Chicago
    - Ec is a reasonable number
    - Put Spaceport in sparsely populated area for 10 mile radius for example
    - If you live next to LAX the numbers are even worse – recall midair over LAX
    - More dangerous to live around LAX than Kennedy Space Port
- Venture Star Operations – they did look at the public safety issue – approached roughly like describing with respect to Ec
- Going inland is a tremendous advantage – most RLVs are not going to be multistage
- Can't get the multistage back – if they are going to be one or two stages the first stage kind of makes up for the fact at low altitude but say you are launched at some place out of Colorado or Utah – advantage is you are not at sea level
- RLVs will never have an ability to do anything but land without avoidance– If ATC moves everyone out of RLV's way then fine. Furthermore, RLVs are very predictable after the deorbit burn. This is the one mitigating factor for easy integration into the air traffic scenario. Furthermore, they are "quick."
    - They won't linger in the airspace plugging up the system. The controllers like these characteristics.
- He considers an airport SUA anyway – can't fly right through it
- Whether it be horizontal takeoff or vertical takeoff there will be a lot of prep time – ATC will be following progress and then begin clearing space and contingent on how big the space has to be there will be a time factor involved
- For X33 had to look for times when it had least amount of impact on air traffic – figured about a 30 minute span of disrupting traffic would do it – get a call to turn left 15 mins while IIP squeezes by or if in middle of path it only took 15 mins to exit thus the ½ hour time frame
- So disruption until all gained confidence that wouldn't sprinkle parts down on everyone
- If you don't give a/c operators notice you will run them out of fuel
- RLV Insurance perspective on certification vs. licensing was not looked at – never crossed that bridge. X-33 was indemnified by US Congress.
- Whole industry wanted to go toward licensing realm instead of certification as it was less intrusive
- It was object oriented
- They want to hear "make sure that bolt never comes out" vs. "put safety wiring on that bolt"
- Ideal cert program is what not how
- Back to overflight and Ec: We can all agree a number on what a casualty is vs. fatality – where we all differ is the reliability calculation that goes into that. How do you determine the reliability numbers. Eng's can come up with but others will say let's look at historical data but no h. data for a long, long time
    - They proposed to FAA why in theory they can launch and fly over Chicago. This was an extreme cost penalty to the program but we felt it was the only way to move forward.

  - So let's take to coast and prove and then move inland
  - Looking at a clean pad – no gantries – erector but no gantries
- Worked on it horizontally but when ready to launch put on a dump truck/hydraulic system the fueled and launched
- How much technology in common with aviation maintenance. A lot, plus two additional areas: cryogenic operations and spacecraft cleanliness requirements.
  - STS before challenger no one used tool control – tool accountability before arriving and departing tools – to prevent tool loss – a/c can't take off until all accounted for
  - When went to do RLV they would incorporate all practices common in aviation, tool control, mx inspection, annuals, periodic inspections, also: high technology – IVHM. Therefore, maintenance personnel will undergo same aircraft type training requirements with the additional awareness of cryogenic ops and cleanliness practices. Attention to detail is the key!! Access to documentation for verification of questionable configuration is the key!! Lean quality control is the key!! Everyone on the maintenance/ops team is an inspector/approver and responsible for the safety of the flight!!
  - If IVHM was advanced enough could relax maintenance activity
- Seen some components on STS like skirt with safety factors as low as 1.09 and was still launched
- How do we get out of test mode? Engine performance and structure to get your margin.
- Add robust subsystems – a lot of the testing on shuttle is testing subsystems – but could kill if not done
- How do get out of test mode? Margin
- Do everything can smartly to get out of mode
- On the ramp at start up – when pilots when out if 90% of the time if stuff didn't work we would figure out something else to do – many of the checks are done ahead of time
- We are not robust enough or have enough margin to put fuel in and try to launch but we have to check everything – not enough margins, they break a lot and just built it (due to stacking of stages)
- When we picked up an airplane from phase depot maintenance couldn't just fly it to the base – would find too many things wrong
- Which is why so hard over on not stacking stages – if you did you would have to find automated ways of checking systems
- Lessons learned document on X-33 and V. Star are more technical and programmatic
- Never wrote down stuff he was telling us
- From technical aspect is there a document or set of documents for review? Refer to NASA.
- Impossibility to do a commercial RLV alone due to funding constraints. You have to have a really cheap design and be able to borrow a lot of money.
- For a small, energetic company to do it you are still talking a couple of a billion of dollars – they did it – company would throw in 1 but needed 5 – impossible without

government sponsorship/funding of some kind. Wall Street will not loan that much money without evidence of a demonstrated cash stream. They consider this venture capital territory—40% interest rate and no where near the amount of money that is actually required.

- If the sensor or global comm Business recovers then possibly low earth orbit satellite business would be one major player – so the only other thing would be tourism if we could get over giggle factor – numerous people would pay big bucks for it
- X-prize is a valuable effort for that purpose but will earn a place in the history books even though costly for prize winner
- OMRSD – after challenger – AS AN EXAMPLE: one of them said that sometime during the flow it takes about 73 days to process the shuttle if everything goes right and sometime during that 73 days someone is to crawl into the cockpit and turn on the APU and go through all switches to ensure all contacts being made than put square in box then have to go undo connector to put test switch on it and then reassemble
- So in 73 days, broke the connector, remade it then retest it and BTW – wasn't that panel working on the last flight 40 days ago?
- WHY are they doing this? Think it's because if 90% of pilots walked and it didn't work he'd be upset so we take it to an absurd limit.
- So don't want a regulation regime that does that

<u>DoD 1: DoD 1 Interview: Air Force Space Plane</u>

23 July 02 Telephone Interview

- satellites, space technology, hypersonics, AF to Space
- (NAI) National Aerospace Initiative being worked and working funding
- Advocating OSD/AF develop Access To Space plan for Military Spaceplane
- NAI also includes hypersonic elements such as old NASP program –
- OTHER LEADS: Gen Lord – 4 Star Commander at SPACECOM, Gen Eberhardt – Commander in Chief, Space Command (CINCSPACE)(a Unified Command) which moved to Omaha – Unified Strategic Air Command
- USAF/AFRL GOALS are not same as NASA goals:
    - Operability Focus
    - Reliability Focus: Aircraft Like Operations
    - Reduce Costs Focus
- Hard problem to quantify reusable military launch system – adhoc group hq'd out of Wright Pat Aero Systems Center
- Useful to start talking to establish a working group to figure how to do this better
- Doesn't believe commercial industry is going to be the pathfinder for something to go into orbit
- NASA not interested in demo vehicle
- 120 study – want to be able to over fly CONUS
- Military Range CC has the call for public safety on military operations

- Commercial – FAA has stick
- If building X Vehicle
- DCX – not sure a functional breakdown but focus from day one was if there was not a high level of reliability then the program was not doable
- Too many unknowns because nobody understood this stuff
- Some operability and high-level objectives accomplished
- Some reports might be available from contractor out of Kirtland AFB
- Boeing Airplane Company tried to lay out process “when build commercial aircraft you know reliability of individual parts” – some in standards and some in historical process
- Before flying first time you have database to give idea of what reliability will be
- helps get over infant mortality
- Mission needs statement gone through JROC on operationally responsive spacelift but doesn’t specify “Spaceplane” or other title
- AF = 2 stage system, LOX, JP for propellant
- National Aerospace Initiative – NAI presentation and technology presentation
- Establish a process for networking

20 Aug 02 Visit to Dayton Interview
Some words on National Aerospace Initiative (NAI)

- Briefed on the X-42 program, AF generic RLV
- Mentioned hydro-carbon engine technology development, however no funding currently exists.
- Mentioned 120 Day Study by NASA and AF, it died, too expensive, scared politicians and leadership.
- NASA working Space Launch Initiative (SLI) with no clear goal or mission other than crew transport for Space Station
- Others have different perspective, want to pursue hypersonic research
- Emphasis on many flight tests during all program phases
- Military wants reusable, responsive, low cost access to space
- Use GOTCHA (Goals, Objectives, Technical Challenges, and Approaches) to define measurable and quantifiable objectives for launch vehicle demonstrator program.
- Differences sited between NASA requirements and AF:

	NASA	**AF**
	Man Rated	Non Man Rated
Payload Needs	50-100 klbs	10-15klb
Responsive	48 Hr	12-24 Hr go to 8 Hr
Launch Rate	20-50 Missions / yr	150 Missions in 2-3 yrs
Weather	Crew safety launch on time	All Wx

- Time frame in three phases: Near Term 2000-2008, Mid Term 2008-2015, Far Term 2015-2025

- Defense Advances Research and Planning Agency (DARPA) to send seed money to develop CONOPS (possible Business Opportunity)
- wants FAA to push developing and approving special flight corridors for testing RLV concepts
- DC-X and FAA work POC (White Sands Missile Range)
- briefed Autonomous Unmanned Aerial Vehicle (UAV) Air Space Conflict Resolution
  - For single engine aircraft failures (i.e. F-16) 40% were human error (pilot) and 36% engine failure (no engine out capability)
  - Looking at "See and Avoid" aspects

Insurance_1:

1. Do you currently, or have you in the past, insured RLV developers/operators for third-party liability?

   No, however, we have policies in place for physical damage and have outlined the basic framework for third-party liability for this same RLV developer. This framework is an extrapolation of that used for expendable launch vehicles. Third party liability insurance for a RLV, the Space Shuttle, was in effect in 1982 for commercial launch missions, until they ended in 1987; and for SpaceHab missions in later years.

2. If yes, can you describe some of the issues that were looked at to determine insurability and the extent of coverage provided?

   The considerations really focus on the maturity of the design and the required Maximum Probable Loss (MPL) calculations required by the licensing rules. At the end of the day, it is the MPL and non-insurance risk management steps taken to reduce any risk to the public that really matter for establishing the insurability and the rate.

3. Does third-party liability coverage extend to any sanctioning government body, e.g., the Federal Aviation Administration?

The commercial liability insurance procured by a licensee for a FAA licensed launch includes the US Government and its agencies as additional insureds.

Above the limit of that required insurance, no. The government currently has a program in place that provides additional indemnification over the $1.5B typically available from the commercial underwriting market. This program, which expires in 2004, is designed to help the industry grow. It has been in place for quite some time – I think we are on the third (or perhaps fourth) extension of the sunset clause.

4. Thinking about the parallels with the aviation industry where third-party liability may be granted for persons on the ground under a flight path, to what extent does the FAA-required certification process impact the insurance rates, both directly and indirectly?

   Again, specific rules, operation, maintenance, or otherwise, are nice, but they really do not have a major impact on a decision to provide coverage. At the end of the day, it is the demonstrated performance of the vehicle. Underwriters look very carefully at the first five launches. If these go well, rates may be lowered somewhat or additional coverage extended. After another fifteen to twenty launches, then another adjustment may be made. Obviously, all of these numbers are relative, but you get the general idea.

   The RLV industry has a lot of parallels to the aviation market immediately following WWI, where you had a lot of little startups with big ideas. We are probably at least ten years out from having a viable RLV market. The RLV developers all want their vehicles considered as airplanes. The insurance market views them as rockets. It's going to take a true transition to "routine" operations before this paradigm shifts. Look at commercial airline operations. They have 1000's of flights per day so their insurance costs end up being spread across millions of Revenue Passenger Miles (RPMs) or a corresponding large number of departures. RLVs have to move from test flights every three or four months to at least a couple of flights per week to be seen as routine by the insurance market.

5. How is risk distributed for RLV developers given that there are so few of them?

   There's an insufficient pool to spread the risk. Right now the risk is spread across the aviation market. There is the potential for pushback from the traditional aviation sector if the losses in the RLV market end up driving up overall aviation rates. We are a long way from that happening now. Again, the real problem for RLV developers is being able to convince the capital market that there is a viable business case to be made; in other words, money to proceed with development is the stumbling block, not lack of insurance.

6. If the FAA were going to impose requirements on vehicle maintenance, what factors would an insurer like to see included in such requirements to ensure risk is managed?

   Can't really say on individual rules. Being able to claim adherence to a set of government rules has historically been a double-edged sword in a courtroom where liability issues are being decided. There is general agreement that the FARs represents a minimum set of requirements. The traditional aviation industry often does much more.

7. Same question for operational rules, both for ground and flight operations?

See #6 above.

8. What do you see as the key factors needed to "normalize" the risk associated with RLVs, i.e., what technical advances, or how many participants for risk-sharing, etc.?

   Demonstrated performance! Just look at Ariane 5. It's an ELV, but its representative of the types of things insurers look at. Ariane 5 has had a total of three launch failures, two of which occurred in the first five launches. Insurers are waiting to see the reliability improve the way it did for Ariane 4. Ariane 4 is nearing a run of 80 successful launches.

9. At what point will you consider RLV operations to be "routine" for relaxing insurance rules/coverage?

   See #4.

10. What would be the differences for "developmental" insurance coverage and passenger-carrying RLVs?

    All RLVs will be considered developmental for some time to come. They must achieve a demonstrated reliability regardless of the rules.

11. Other Comments

    Insurance for the space operations (RLV or ELV) is provided by a single worldwide market centered in London and Europe. Most of the third-party liability also is underwritten by entities primarily in Europe.

    There have been previous attempts to look at the role that insurance plays in the development of a new high-risk technology such as RLVs. These studies have been inconclusive.

    It's unclear what effect, if any, a change in the way safety of an RLV is determined would have on the provision for insurance. Since the probability of failure for the vehicle is incorporated into the MPL calculation, would not expect there to be much effect. A more difficult question is how do you account for the fact that most of the risk occurs early in the flight, i.e. how do address varying risk throughout the flight profile. We don't have an answer for this question yet.

    At the end of the day, it unreasonable to think that we will not have a learning curve with RLVs. After all, it took approximately twenty flights before we realized flying the Shuttle at low temperatures was a problem.

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